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RESEARCH MEMORANDUM

PERFORMANCE OF PURE FUELS IN A SINGLE J33 COMBUSTOR

III - FIVE HYDROCARBON GASEOUS FUELS AND ONE OXYGENATED-HYDROCARBON GASEOUS FUEL

By Arthur L. Smith and Jerrold D. Wear

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
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SUMMARY

Investigations of pure gaseous fuels, five hydrocarbons and one oxygenated hydrocarbon, were conducted in a single tubular-type combustor in order to determine possible relations between combustor performance and fuel properties. The fuels tested were propane, ethane, ethylene, acetylene, 1,3-butadiene, and ethylene oxide. Combustor temperature rise and combustion efficiency were determined for each fuel over a range of heat-input and air-flow rates at two inlet-air total-pressure conditions and one inlet-air total temperature. Data were obtained with two fuel-injector configurations. Combustor blow-out limits were obtained for some of the fuels over the range of test conditions.

At the more severe operating conditions investigated, the data indicated an increase in combustion efficiency with an increase in maximum burning velocity, an increase in flammability range, and a decrease in minimum spark-ignition energy. The fuels that exhibited the highest combustion efficiencies, in general, were ethylene oxide and acetylene; while those exhibiting the lowest combustion efficiencies were propane and ethane. Gaseous-fuel penetration and distribution in the primary combustion zone markedly altered combustion efficiencies; when fuel-injector capacity was varied, higher efficiencies were generally obtained with a smaller-capacity fuel injector.

INTRODUCTION

Research is being conducted at the NACA Lewis laboratory to obtain information on the relative effects of such factors as fuel-spray evaporation, turbulent-flame spreading, and chemical-reaction rate on the performance of turbojet combustors. Part of this research is designed to provide information on the combustion characteristics of pure liquid

and gaseous fuels and, particularly, to determine whether combustor performance can be related to physical or fundamental combustion properties of these fuels or both.

The present investigation is the final phase of a three-phase program on the performance of pure fuels in a single J33 combustor. In the first phase of this program (ref. 1), combustor performance was determined with five liquid hydrocarbon fuels, which represent a range of physical and fundamental combustion properties. The data indicated an approximately linear increase in temperature rise and combustion efficiency at constant heat input with increase in maximum burning velocity. However, the range of fuel properties considered was too small to establish a conclusive correlation. Accordingly, a second investigation (ref. 2) was conducted with 13 liquid hydrocarbon and nonhydrocarbon fuels having a wider range of physical and fundamental combustion properties. An approximate correlation was obtained between combustion efficiency at a constant heat input and the parameter $u_x/L_v^{1/3}$, where u_x is the maximum burning velocity and L_v is the latent heat of vaporization at the normal boiling point.

The results reported in reference 2 suggest that the rate-controlling process changes with fuel properties. For example, the combustion rate of a low-flame-speed fuel might be limited by its flame speed; whereas the combustion rate of a high-flame-speed fuel might be limited by its vaporization characteristics. For gaseous fuels, where the vaporization step is eliminated, the results of reference 2 suggest that the effect of fuel type on combustion efficiency might be treated solely in terms of maximum burning velocity. Accordingly, the present and final phase of the program on the performance of pure fuels in a single J33 combustor was conducted with gaseous fuels.

The combustion performances of propane, ethane, ethylene, acetylene, 1,3-butadiene, and ethylene oxide were investigated over a range of airflow and fuel-flow rates and at two inlet-air pressures (14.3 and 8.0 in. Hg abs). The inlet-air temperature was held constant at approximately 200° F. The effect of fuel-air distribution and mixing on combustor performance was investigated by using two different modified commercial nozzles.

The performances of the fuels are compared on the basis of combustion efficiency at a heat-input value of 200 Btu per pound of air. The effect of physical properties on combustor performance was minimized to some degree by using gaseous fuels; consequently, the variations in performance were considered only in terms of fundamental combustion properties of the fuels. The fundamental combustion properties examined for possible relations with performance are spontaneous-ignition temperature, minimum spark-ignition energy, flammability range, and maximum burning velocity. The results are compared with those obtained in references 1 and 2.

FUELS

Fundamental combustion properties of the six gaseous fuels used in the investigation are summarized in table I. Purity values listed in the table were obtained from the supplier.

APPARATUS AND INSTRUMENTATION

With the exception of the fuel system and fuel nozzle, the apparatus and instrumentation used in this investigation were the same as those in reference 2.

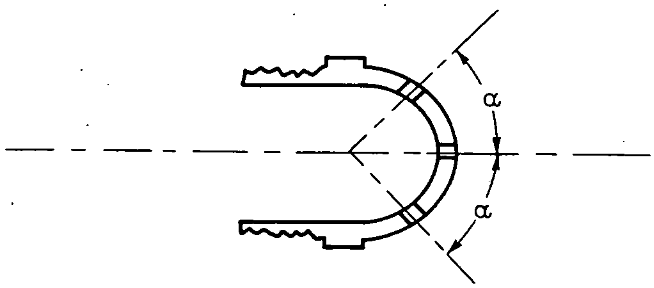
A diagram of the general arrangement of the single J33 combustor and the auxiliary equipment is shown in figure 1. Air flow to the combustor was measured by a square-edge orifice plate installed according to A.S.M.E. specifications and located upstream of all regulating valves. The combustor inlet-air flow rate and pressure were regulated by remote-controlled valves in the laboratory air-supply and exhaust system. The air supplied to the combustor had a dew point of either -20° or -70° F.

A diagrammatic cross section showing the combustor and its auxiliary ducting, the position of the instrumentation planes, and the location of temperature- and pressure-measuring instruments in the instrumentation planes is presented in figure 2. Thermocouples and total-pressure tubes in each instrumentation plane were located at centers of equal annular area. Construction details of the temperature- and pressure-measuring instruments are shown in figure 3.

The fuel system used in the present investigation is illustrated schematically in figure 4. The gaseous fuels were drawn from cylinders, through a reducing valve and a steam-fed heat exchanger into the combustor. For tests with ethylene oxide, the reducing valve was replaced by a fine-mesh-screen flash-back arrester. A water-trap flash-back arrester was placed downstream of the reducing valve for tests with acetylene.

Fuel-flow rates to the combustor were measured by rotameters. The rotameters were calibrated with air at temperature and pressure conditions that provided densities approximately the same as those of the test fuels at the test conditions. Appropriate density corrections were then applied to the rotameter measurements.

Two fuel-nozzle-injector configurations were used to obtain a variation in injector characteristics. The swirl parts were removed from a commercial hollow-cone swirl-type nozzle. Six equally spaced holes were drilled at an angle α from the axis of the nozzle (see the following illustration). The normal discharge orifice (0.016-in. diam.) was not altered.



The variations in injector design were as follows:

	Angle, α, deg	Hole diameter, in.
Configuration 1 (small-capacity nozzle)	57	1/16
Configuration 2 (large-capacity nozzle)	45	1/8

PROCEDURE

The performances of the six gaseous fuels were determined at the following combustor operating conditions:

Inlet-air total pressure, in. Hg abs	Inlet-air mass flow, lb/sec	Inlet-air total temperature, °F	Inlet-air velocity, ft/sec[a]
14.3	0.6	200	79
	.8		105
	1.0		132
	1.3		170
8.0	0.36	200	80
	.56		130
	.73		170

[a]Based on combustor maximum cross-sectional area of 0.267 sq ft measured $12\frac{1}{2}$ inches downstream of section B-B (fig. 2).

The procedures for establishing test conditions and recording data were identical to those described in reference 2. Reproducibility of the data was determined from occasional tests with propane and the small-capacity fuel nozzle. Tests with 1,3-butadiene were limited because of the small quantity of this fuel available.

CALCULATIONS

Combustor Temperature Rise

The combustor temperature rise was determined as the increase in gas temperature from section B-B to C-C (fig. 2). The temperature at B-B was the average indication of the two iron-constantan thermocouples; the temperature at C-C was the arithmetic average indication of the 16 chromel-alumel thermocouples. The indicated thermocouple readings were taken as true values of the total temperature.

Combustion Efficiency

Combustion efficiency was defined as

$$\frac{\text{Actual enthalpy rise across combustor}}{(\text{Fuel-air ratio})(\text{Lower heating value of fuel})}$$

The equations and charts of reference 3 were used to calculate combustion efficiencies for the hydrocarbon fuels. The combustion efficiency for ethylene oxide was calculated by using the procedure presented for oxygenated-hydrocarbon fuels in reference 2.

RESULTS

Combustor performance data for the six gaseous fuels obtained in a single J33 combustor are presented in table II. In order to place the performances of the various fuels on a comparable basis, heat input (product of fuel-air ratio and lower heat of combustion of the fuel) was used in place of fuel-air ratio as one independent variable. Relations among heat input, combustor temperature rise, and combustion efficiency for each of the fuels are shown in figures 5 to 10. The curves of constant combustion efficiency were calculated for each fuel. Combustor blow-out points are also shown in these figures.

The reproducibility of the test data is indicated in figures 5(a) and (b). Combustor performance data were obtained periodically with propane fuel over a period of five months, during which time the combustor was disassembled and cleaned several times. The average percentage deviation of the combustion efficiency of individual data points from the curves faired through all the data was about ±1 percent; the maximum deviation was about 4 percent. Accordingly, differences greater than 2 percent among fuels may generally be considered as real differences, while differences less than 2 percent fall within the reproducibility range. Blow-out data could be checked closely at the time obtained, although comparable data obtained over a period of time varied to some degree.

The data of figures 5 to 10 show, in general, a progressive increase in temperature rise with heat input up to the rich blow-out point or facility limiting points. However, rich-blow-out points for propane (fig. 5), ethane (fig. 6), and 1,3-butadiene (fig. 7) sometimes occurred at a heat input higher than that required for maximum temperature rise. Heat input at rich blow-out decreased, in general, with increase in inlet-air mass-flow rates and with decrease in inlet-air total pressures. Rich-blow-out points were not obtained for some of the fuels because of limitations imposed by the facilities. These points and the rich-blow-out points determined are indicated by assigned symbols.

Maximum temperature rise usually increased with an increase in inlet-air total pressure and a decrease in inlet-air mass-flow rate. For a given fuel, the maximum temperature rise obtained with the small-capacity fuel nozzle was generally greater than that obtained with the large-capacity fuel nozzle. The highest combustor-temperature-rise value, about 2000° F, which represents an instrumentation limit, was obtained with ethylene and acetylene.

Combustion efficiencies increased, in general, with increase in inlet-air total pressure and with decrease in inlet-air mass-flow rates for all the fuels tested in this investigation. Representative combustion-efficiency data, which illustrate the effect of fuel-injector configuration and heat input on combustion efficiency, are presented for one inlet-air reference velocity and two inlet-air total-pressure conditions in figure 11. The curves, which are presented for ethane, ethylene oxide, and acetylene, show the tendency toward lower combustion efficiencies with use of the large-capacity fuel injector. The one exception was ethylene oxide. For this fuel the small-capacity fuel injector tended to give lower combustion efficiencies. In figure 11, combustion efficiency passes through a sharp maximum with increase in heat input for ethane with the small-capacity fuel injector at the high inlet-air total-pressure condition, but the curve remains relatively flat for acetylene. The performance of propane was similar to that of ethane, while the performances of the remaining fuels were similar to that of acetylene. The spread in combustion efficiency among fuels increased as the severity of the test conditions increased.

DISCUSSION

The objective of the investigation reported herein is to relate the combustion performances of the various fuels to fundamental combustion characteristics of the fuels. One representative combustion performance parameter, combustion efficiency at a heat-input value of 200 Btu per pound of air, was chosen for making comparisons among the fuels. The heat-input value of 200 Btu per pound of air was the maximum heat-input value at which data were available for all fuels.

Comparison of Combustion Efficiencies of Gaseous Fuels

In figure 12, combustion efficiency at a heat-input value of 200 Btu per pound of air is plotted against air-flow rate for each fuel. Data are presented for two inlet-air total pressures (8.0 and 14.3 in. Hg abs) and for two fuel-injector configurations. At low inlet-air mass-flow rates the combustion efficiencies of all the fuels are high, in most cases 90 percent or greater. Thus, differences in the fundamental combustion properties of the test fuels are of negligible importance at this condition. An increase in inlet-air mass-flow rate and, consequently, air velocity resulted in a decrease in combustion efficiency and an increase in the variation in combustion efficiency with fuel type. The high-performance fuels (ethylene oxide and acetylene) were less affected by changes in inlet-air mass-flow rates than the other fuels. At severe operating conditions the fuels that exhibited the lowest combustion efficiencies, in general, were propane and ethane, while those that exhibited the highest combustion efficiencies were ethylene oxide and acetylene. The difference between ethane and ethylene oxide was approximately 46 percent at the low inlet-air total pressure and with the large-capacity fuel nozzle and a high inlet-air mass flow rate. In figure 12 it may be seen that the performance order of the fuels changed with operating conditions; consequently, no single correlation between combustion efficiency and fuel properties would be effective over the entire combustor operating range.

The tests with different fuel injectors showed that changes in the fuel-distribution patterns in the combustor altered not only the combustion efficiency of the combustor but also the magnitude of the efficiency differences between the fuels. At the same fuel-flow rate, the small-capacity fuel injector with its wider cone angle and higher pressure drop may have distributed the gaseous fuel to form the more homogeneous fuel-air mixture pattern in the primary combustion zone that resulted in the higher combustion efficiencies observed.

Comparison of Combustion Efficiency with Fundamental Combustion Properties

Some fundamental combustion properties of fuels that may affect combustor performance are spontaneous-ignition temperature, flammability range, minimum spark-ignition energy, and maximum burning velocity. An increase in flammability range or maximum burning velocity, or a decrease in minimum ignition energy or spontaneous-ignition temperature might be expected to effect increases in the rate of the combustion process. The variation in combustion efficiency at a heat-input value of 200 Btu per pound of air with fundamental combustion properties of the gaseous fuels is shown in figure 13. Minimum spark-ignition-energy data were estimated

from the curves of reference 4 at the pressures used in the combustor tests. Data are presented for two inlet-air total pressures (8.0 and 14.3 in. Hg abs), one inlet-air temperature (200° F), one inlet-air reference velocity (170 ft/sec), and two fuel-injector configurations. The data indicate an increase in combustion efficiency with an increase in maximum burning velocity (figs. 13(a) and (b)), a decrease in minimum spark-ignition energy (figs. 13(a) and (b)), and an increase in flammability range (figs. 13(c) and (d)). There is no satisfactory relation between spontaneous-ignition temperature and combustion efficiency (figs. 13(c) and (d)), although a slight trend toward a decrease in combustion efficiency with increase in spontaneous-ignition temperature is noted.

In references 1 and 2, similar combustion performance data were obtained with liquid hydrocarbon and nonhydrocarbon fuels in the same combustor but with a different fuel injector. In reference 1, there was some evidence of a relation between combustion performance of liquid hydrocarbon fuels and maximum burning velocity. No well-defined relation between combustion performance and minimum spark-ignition energy was indicated, although there was a qualitative trend toward increasing combustion efficiency with decreasing minimum spark-ignition energy. Similar results are reported for liquid hydrocarbon and nonhydrocarbon fuels in reference 2. That is, of the fundamental combustion properties considered, maximum burning velocity provided the best correlation with combustion performance. Since minimum spark-ignition energy has been related to maximum burning velocity (refs. 4 and 5), relations similar to those established with maximum burning velocity would be expected. The fact that generally more satisfactory correlations have been observed with maximum burning velocity may be attributed to the greater inherent errors associated with obtaining minimum-spark-ignition-energy data.

Comparisons of the variation in combustion efficiency with maximum burning velocity for the gaseous and liquid hydrocarbon and nonhydrocarbon fuels for the same operating conditions are presented in figure 14. The solid curve is faired through all the liquid-fuel data from references 1 and 2, while the broken curves are faired through all the gaseous-fuel data obtained in this investigation. Combustion efficiencies from references 1 and 2 were obtained at a heat-input value of 200 Btu per pound of air. Combustion efficiencies for both the liquid and the gaseous fuels increased with an increase in maximum burning velocity at severe conditions. At a given value of maximum burning velocity, the combustion efficiency obtained with a gaseous fuel was, in general, appreciably higher than that obtained with a liquid fuel. The improvement in combustion efficiency with the use of gaseous fuels might be attributed, at least partly, to the elimination of the fuel-vaporization step. The influence of the fuel-vaporization step on the over-all combustion process is also indicated by the correlation obtained with liquid fuels in reference 2 in which an improved correlation was obtained by considering both maximum burning velocity and latent heat of vaporization.

Since combustion efficiencies of the gaseous fuels were affected by changes in fuel-injector configurations, the differences in performance of the liquid and gaseous fuels cannot be attributed solely to the elimination of the fuel-vaporization step. The effectiveness of mixing apparently must also be considered.

SUMMARY OF RESULTS

The following results were obtained from an investigation of the effects of fundamental combustion properties of six pure gaseous fuels on the performance of a single tubular combustor.

1. At severe operating conditions, the data indicated an increase in combustion efficiency with an increase in maximum burning velocity and flammability range and a decrease in minimum spark-ignition energy. The fuels exhibiting the highest performance were ethylene oxide and acetylene, while the fuels exhibiting the lowest performances were propane and ethane.

2. An increase in inlet-air mass-flow rate or decrease in inlet-air pressure generally decreased combustion efficiency and increased differences in combustion efficiencies among the fuels.

3. The combustion efficiencies obtained with a smaller-capacity fuel injector were higher, in general, than those obtained with a larger-capacity fuel injector.

4. Combustion efficiencies obtained with the gaseous fuels were generally higher than those obtained with liquid fuels in a previous investigation at the same combustor operating conditions.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, November 7, 1955

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TABLE I. - FUNDAMENTAL COMBUSTION PROPERTIES OF GASEOUS FUELS

Fuel	Estimated purity, percent	Lower heat of combustion, Btu/lb	Minimum ignition energy, joules (a)	Spontaneous ignition temperature in air, °F (b)	Flammability range, percent stoichiometric, (rich minus lean) (c)	Maximum burning velocity, cm/sec
Propane	99.8	[d]19,929	2.50×10^{-4}	920	174.3	[e]39.0
Ethane	95.0	[d]20,416	2.40	882	165.0	[e]40.1
Ethylene	95.0	[d]20,276	1.24	914	440.9	[e]68.3
Acetylene	100	[d]20,734	0.51	581	633.0	[f]140.0
1,3-Butadiene	98.0	[g]19,180	1.60	784	255.0	[e]54.5
Ethylene oxide	99.5	[h]11,748	0.87	804	997.2	[f]90.0

[a]Refs. 4 and 5.

[b]Ref. 6.

[c]Ref. 7.

[d]Ref. 8.

[e]Ref. 9.

[f]Data from ref. 10 corrected by a factor from ref. 9.

[g]Ref. 11.

[h]Ref. 12.

TABLE II. - PERFORMANCE DATA FROM SINGLE COMBUSTOR OPERATING WITH HYDROCARBON AND OXYGENATED-HYDROCARBON GASEOUS FUELS

[Combustor-inlet total temperature, 660° R]

(a) Propane; fuel-nozzle configuration 1

Run	Air flow, lb/sec	Combustor-inlet reference velocity (nominal), ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Fuel-nozzle differential pressure, lb/sq in.	Fuel temperature, °F	Heat input, Btu/lb	Mean combustor-outlet temperature, °F	Mean temperature rise through combustor, °F	Combustion efficiency, percent	Remarks
Combustor-inlet total pressure, 14.3 in. Hg abs											
1	0.597	79	15.5	0.0072	4.8	99	143.7	1215	556	97.9	
2	.598		19.8	.0092	8.8	92	183.2	1410	746	104.9	
3	.599		25.1	.0116	12.6	91	231.4	1565	905	102.3	Inlet pressure unsteady
4	.596		32.1	.0150	17.0	89	298.4	1730	1073	95.9	Resonance, blow-out
5	.596		45.7	.0213	25.3	87	424.7	2000	1340	87.0	Inlet pressure unsteady
6	1.301	170	21.0	.0045	10.3	84	89.3	920	262	72.6	
7	1.302		28.5	.0061	14.2	84	121.2	1045	385	79.4	
8	1.302		35.7	.0076	19.1	83	152.1	1160	500	83.1	
9	1.302		43.9	.0094	25.5	83	186.8	1270	613	83.8	
10	1.299		28.4	.0061	16.0	100	121.2	1095	435	90.0	
11	1.299		35.1	.00751	19.5	109	149.7	1175	515	87.0	
12	1.301		44.1	.0094	25.1	114	187.8	1275	615	83.7	
13	1.300		64.9	.0139	39.7	117	276.2	1345	688	64.7	
14	1.299		70.0	.0150	45.3	99	298.4	1335	675	59.0	Blow-out
15	1.313		24.9	.0053	12.9	112	105.2	1005	343	81.1	
16	1.297		36.9	.0079	20.3	109	157.7	1185	525	84.3	
17	1.296		51.0	.0109	30.5	99	217.9	1350	689	81.6	
18	1.295		58.0	.0125	35.8	84	248.1	1360	698	72.9	
19	1.295		66.0	.0142	40.5	83	282.4	1355	694	64.0	
20	1.297		67.9	.0145	42.3	81	289.8	1310	651	58.4	Blow-out
21	.598	79	16.5	.0077	5.8	81	152.7	1265	601	100.1	
22	.598		26.0	.0121	13.8	81	240.8	1610	949	103.5	
23	.593		33.3	.0156	19.2	81	311.1	1825	1164	100.5	
24	.593		39.8	.0187	22.8	81	372.1	1940	1279	93.8	Resonance
25	.593		45.7	.0214	27.2	81	426.7	2030	1369	88.7	Resonance, blow-out
26	.600		15.3	.0071	5.0	77	140.9	1220	557	100.0	
27	.600		26.8	.0124	14.3	76	247.0	1635	975	104.0	
28	.600		40.5	.0187	23.1	77	373.5	1940	1279	93.4	Resonance
29	1.305	170	16.7	.0035	6.0	77	70.6	865	204	71.2	
30	1.302		36.5	.0078	20.3	75	155.1	1180	526	85.8	
31	1.300		49.3	.0105	30.0	74	209.9	1320	660	80.9	
32	.597	79	16.9	.0078	6.0	73	156.3	1265	608	98.9	
33	.597		24.5	.0114	12.8	73	227.8	1555	901	103.7	
34	.597		37.4	.0174	20.8	73	346.8	1875	1213	94.7	Resonance
35	1.300	170	22.8	.0049	10.8	74	97.1	960	300	76.7	
36	1.303		34.0	.0072	18.3	74	144.2	1145	486	85.0	
37	1.301		46.7	.0100	28.0	74	199.3	1315	659	85.0	
38	.799	105	9.0	.0031	1.6	71	62.5	860	201	79.1	
39	.800		16.1	.0056	5.0	71	111.0	1075	417	93.9	
40	.801		21.8	.0076	10.0	71	150.7	1275	617	104.6	
41	.799		30.6	.0106	16.0	72	211.9	1470	812	99.4	
42	.799		40.2	.0140	23.2	72	278.4	1675	1017	96.8	
43	.800		56.0	.0194	33.7	72	387.2	1845	1187	83.3	Blow-out
44	.598	79	8.5	.0039	1.4	74	78.3	935	275	86.8	
45	.598		14.4	.0067	4.1	74	133.0	1180	520	98.7	
46	.598		20.0	.0091	8.5	74	181.3	1390	730	103.5	
47	.598		24.6	.0114	13.0	73	228.0	1570	910	104.4	
48	.597		33.6	.0156	18.0	73	311.7	1785	1126	96.8	Slight resonance
49	.598		42.6	.0198	24.3	73	394.2	1975	1315	91.5	Blow-out
50	.997	132	14.7	.0041	3.1	71	81.7	870	213	64.3	
51	.998		21.1	.0059	9.6	71	117.3	1110	453	96.8	
52	1.000		27.2	.0076	14.5	71	150.5	1270	613	103.5	
53	.999		40.3	.0112	22.7	71	223.0	1480	820	95.6	
54	.999		45.6	.0127	27.2	71	252.5	1560	900	93.5	
55	1.003		63.1	.0175	37.4	70	348.2	1615	959	73.5	Blow-out
56	1.299	170	22.5	.0048	10.8	71	95.7	955	295	76.4	
57	1.297		34.4	.0074	18.7	71	147.0	1150	490	84.1	
58	1.301		52.8	.0113	32.0	71	224.6	1345	686	78.8	
59	1.305		67.5	.0144	41.3	71	286.4	1365	706	64.3	
60	1.303		69.4	.0148	42.3	71	295.0	1360	700	61.9	Blow-out
61	1.302		24.3	.0052	11.8	72	103.4	800	300	70.8	
62	1.304		37.3	.0079	20.1	72	158.2	1005	505	79.1	
63	1.302		53.6	.0114	31.3	72	227.8	1155	653	72.2	
64	1.303		67.2	.0143	39.7	72	285.6	1120	617	54.7	Resonance, blow-out
65	.997	132	17.5	.0049	6.0	73	97.4	815	314	78.6	
66	.997		24.0	.0067	11.7	72	133.0	1020	517	96.1	
67	.997		31.3	.0087	17.6	72	173.9	1200	698	100.8	

TABLE II. - Continued. PERFORMANCE DATA FROM SINGLE COMBUSTOR OPERATING WITH HYDROCARBON AND OXYGENATED-HYDROCARBON GASEOUS FUELS

[Combustor-inlet total temperature, 660° R]

(a) Concluded. Propane; fuel-nozzle configuration 1

Run	Air flow, lb/sec	Combustor-inlet reference velocity (nominal), ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Fuel-nozzle differential pressure, lb/sq in.	Fuel temperature, °F	Heat input, Btu/lb	Mean combustor-outlet temperature, °F	Mean temperature rise through combustor, °F	Combustion efficiency, percent	Remarks
Combustor-inlet total pressure, 14.3 in. Hg abs - Concluded											
68	0.799	105	14.1	0.0050	4.1	72	97.5	855	355	89.0	Inlet pressure unsteady
69	.797		19.4	.0068	7.7	72	135.0	1035	534	97.9	
70	.796		36.8	.0129	19.6	72	256.0	1445	944	94.9	
71	.590	79	9.9	.0047	1.9	72	92.7	835	335	88.3	
72	.599		10.4	.0048	1.9	73	96.5	840	340	86.1	
73	.599		15.9	.0074	4.6	73	146.6	1085	586	99.3	
74	.598		31.1	.0145	15.8	73	288.2	1565	1066	96.3	Resonance
75	1.000	132	39.9	.0111	23.2	78	221.0	1485	823	96.8	
76	.600	79	14.2	.0066	4.1	78	131.2	1185	524	100.7	
77	.601		33.3	.0154	18.6	78	307.3	1800	1140	99.5	Slight resonance
78	1.303	170	22.8	.0049	11.3	99	96.8	950	290	74.3	
79	1.304		36.3	.0077	19.5	101	154.3	1170	511	83.7	
80	1.304		58.5	.0125	34.7	105	248.5	1365	705	73.6	
81	.902	132	14.3	.0044	3.6	98	87.9	900	240	67.5	
82	.902		21.6	.0066	9.3	97	132.3	1115	454	86.2	
83	.904		71.6	.0220	43.1	95	438.2	1635	974	60.2	Blow-out
84	.798	105	12.4	.0043	2.8	91	85.7	960	299	86.5	
85	.798		26.6	.0093	14.1	89	184.7	1420	760	106.0	
86	.798		44.0	.0153	25.0	90	305.3	1710	1050	91.7	
87	.598	79	10.8	.0050	1.9	88	99.8	1030	369	92.1	
88	.598		16.9	.0078	5.8	90	156.2	1275	614	100.0	
89	.596		33.9	.0158	18.0	103	314.3	1775	1113	94.9	
90	.597		48.3	.0225	26.2	120	447.8	1985	1325	81.8	Resonance, blow-out
Combustor-inlet total pressure, 8.0 in. Hg abs											
91	0.718	105	17.9	0.0069	9.8	82	138.1	1035	380	68.9	
92	.718		24.4	.0095	15.4	82	188.6	1175	520	70.9	
93	.717		27.1	.0105	17.4	82	208.8	1180	523	63.9	
94	.717		30.3	.0117	20.4	82	233.4	1135	475	52.0	Blow-out
95	.716		28.7	.0111	19.9	82	222.0	1160	500	57.5	
96	.727		15.2	.0058	7.4	75	115.8	970	312	67.1	
97	.727		22.3	.0085	11.9	75	169.8	1115	459	68.3	
98	.727		25.3	.0097	16.2	75	192.5	1180	517	68.4	
99	.727		29.2	.0111	20.2	75	222.6	1160	497	57.0	Blow-out
100	.562	130	7.8	.0038	2.5	74	76.7	845	185	59.5	
101	.562		10.8	.0053	4.2	74	106.3	970	310	72.5	
102	.562		13.2	.0065	5.4	74	129.9	1075	415	80.1	
103	.562		15.6	.0077	7.8	75	153.7	1185	525	86.4	
104	.562		20.8	.0103	12.1	75	204.7	1365	705	88.7	
105	.562		23.8	.0118	15.9	75	234.4	1400	740	81.8	
106	.562		31.6	.0156	19.6	75	311.3	1350	690	57.9	Blow-out
107	.730	170	14.4	.0055	7.1	70	109.0	925	264	60.2	
108	.729		20.4	.0078	11.6	70	155.2	1100	440	71.4	
109	.729		28.6	.0109	18.9	70	217.2	1140	480	56.3	
110	.728		28.4	.0108	18.7	70	216.0	1160	498	58.8	
111	.730		30.9	.0118	20.5	70	234.8	1120	460	50.0	Blow-out
112	.354	80	8.2	.0064	2.7	75	127.8	1130	470	92.4	
113	.354		10.7	.0084	4.2	75	166.6	1280	623	95.3	
114	.353		14.0	.0110	6.7	75	219.4	1430	767	90.6	
115	.354		18.0	.0141	9.8	75	281.2	1630	970	91.3	
116	.354		22.4	.0176	13.6	75	351.0	1775	1112	85.4	Blow-out
117	.726	170	20.3	.0078	11.6	79	155.1	1090	429	69.7	
118	.727		28.3	.0108	19.1	79	215.4	1150	489	57.8	
119	.561	130	12.9	.0064	56.7	79	127.2	1075	412	81.2	
120	.560		20.7	.0103	12.2	79	204.7	1375	712	89.7	
121	.544		9.2	.0047	2.7	106	94.1	915	254	66.9	
122	.558		9.8	.0049	3.3	104	97.1	930	269	68.7	
123	.558		15.3	.0076	7.0	104	151.6	1155	494	82.3	
124	.558		27.4	.0136	16.2	104	271.8	1405	742	71.2	
125	.747	170	15.9	.0059	7.7	101	117.6	925	263	55.7	
126	.725		15.1	.0058	4.0	99	115.2	935	269	58.1	
127	.725		19.1	.0073	10.7	98	145.6	1060	399	68.9	
128	.725		25.6	.0098	16.7	97	195.2	1175	514	67.0	
129	.725		27.7	.0106	18.2	96	211.7	1160	499	60.1	
130	.725		33.6	.0129	21.6	95	256.7	1120	457	45.6	Blow-out

TABLE II. - Continued. PERFORMANCE DATA FROM SINGLE COMBUSTOR OPERATING WITH HYDROCARBON AND OXYGENATED-HYDROCARBON GASEOUS FUELS

[Combustor-inlet total temperature, 660° R]

(b) Propane; fuel nozzle configuration 2

Run	Air flow, lb/sec	Combustor-inlet reference velocity (nominal), ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Fuel-nozzle differential pressure, lb/sq in.	Fuel temperature, °F	Heat input, Btu/lb	Mean combustor-outlet temperature, °F	Mean temperature rise through combustor, °F	Combustion efficiency, percent	Remarks
Combustor-inlet total pressure, 14.3 in. Hg abs											
131	0.595	79	30.6	0.0143	3.0	89	284.4	1675	1018	94.9	Inlet pressure unsteady
132	.599		16.5	.0077	.15	73	152.7	1260	597	99.4	
133	.600		23.2	.0108	.20	72	214.3	1475	812	98.4	
134	.598		32.0	.0149	1.13	72	296.2	1775	1116	100.7	
135	.598		40.3	.0187	1.37	72	372.5	1930	1271	93.0	Resonance
136	.598		47.1	.0219	1.61	72	436.1	2050	1386	88.1	Blow-out
137	.602		33.3	.0154	1.13	73	306.9	1770	1109	96.7	
138	1.299	170	16.2	.0035	0	74	69.0	885	226	80.7	
139	1.297		24.4	.0052	0	74	104.0	980	327	78.1	
140	1.298		38.7	.0083	.44	74	164.8	1095	434	66.5	
141	1.299		48.6	.0104	1.61	72	207.1	1185	524	64.6	
142	1.298		58.9	.0126	3.13	71	251.3	1245	591	60.6	
143	1.298		60.4	.0129	3.35	71	257.7	1235	575	57.5	Blow-out
144	.600	79	7.0	.0032	0	78	64.4	905	245	93.7	
145	.601		13.6	.0063	.05	78	124.8	1125	466	93.8	
146	.598		18.3	.0085	.15	78	169.2	1330	667	100.8	
147	.598		25.8	.0120	.39	78	238.6	1530	868	95.1	
148	.597		33.0	.0154	.73	78	306.1	1725	1064	92.8	
149	.599		44.0	.0204	1.61	77	406.4	1965	1306	88.2	Resonance
150	.596		47.0	.0219	1.71	78	436.3	2035	1375	87.2	Resonance, blow-out
151	.781	105	7.9	.0028	0	79	56.0	880	221	97.0	
152	.800		11.5	.0040	0	79	79.3	950	293	91.3	
153	.800		19.7	.0068	0	79	136.1	1170	510	94.5	
154	.800		28.3	.0098	.39	79	195.7	1360	700	92.0	
155	.796		37.9	.0132	1.13	78	263.3	1575	918	91.7	
156	.797		50.5	.0176	2.10	78	350.6	1755	1097	84.2	
157	.799		57.2	.0199	2.64	78	396.0	1790	1132	77.6	Blow-out
158	.997	132	10.9	.0030	0	79	60.6	880	224	90.9	
159	1.000		20.2	.0056	0	79	112.0	1060	401	89.5	
160	1.000		33.3	.0093	.39	79	184.5	1265	607	84.0	
161	.997		49.0	.0137	1.6	79	272.2	1460	800	76.9	
162	1.001		64.2	.0178	3.5	79	355.1	1465	883	66.2	Blow-out
163	1.302	170	15.7	.0034	0	79	66.8	880	219	80.8	
164	1.300		26.6	.0057	0	79	113.2	995	338	74.4	
165	1.298		37.7	.0081	.15	79	160.8	1090	431	67.6	
166	1.305		49.7	.0106	1.37	79	210.9	1160	500	60.5	
167	1.304		66.9	.0143	3.72	79	284.0	1225	565	51.5	Blow-out
Combustor-inlet total pressure, 8.0 in. Hg abs											
168	0.725	170	14.2	0.0055	0.20	72	108.6	895	231	52.8	
169	.725		20.2	.0077	.29	73	154.3	940	278	45.2	
170	.725		26.2	.0100	1.03	73	199.9	960	302	38.1	
171	.559	130	8.7	.0043	0	75	86.5	955	295	84.5	
172	.559		15.0	.0075	.05	75	148.9	1060	399	67.4	
173	.561		20.5	.0102	.54	75	202.7	1160	499	62.7	
174	.560		27.3	.0135	1.03	75	269.8	1225	564	54.0	
175	.560		30.6	.0152	1.22	75	301.9	1230	569	48.9	Blow-out
176	.724	170	9.8	.0038	0	76	74.9	855	196	64.5	
177	.725		11.7	.0045	0	77	89.1	875	214	59.4	
178	.725		13.4	.0051	0	77	102.2	890	229	55.5	
179	.729		15.2	.0058	0	77	115.2	895	234	50.5	Blow-out
180	.356	80	7.9	.0062	0	72	123.2	1075	416	84.6	
181	.356		10.7	.0084	.05	72	166.4	1230	572	87.3	
182	.355		14.1	.0111	.29	72	220.4	1395	731	85.8	
183	.352		17.1	.0135	.29	72	269.4	1535	874	85.2	
184	.355		21.4	.0167	1.03	72	333.0	1705	1043	83.9	Blow-out

TABLE II. - Continued. PERFORMANCE DATA FROM SINGLE COMBUSTOR OPERATING WITH HYDROCARBON AND OXYGENATED-HYDROCARBON GASEOUS FUELS

[Combustor-inlet total temperature, 660° R]

(c) Ethane; fuel-nozzle configuration 1

Run	Air flow, lb/sec	Combustor-inlet reference velocity (nominal), ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Fuel-nozzle differential pressure, lb/sq in.	Fuel temperature, °F	Heat input, Btu/lb	Mean combustor-outlet temperature, °F	Mean temperature rise through combustor, °F	Combustion efficiency, percent	Remarks
Combustor-inlet total pressure, 14.3 in. Hg abs											
185	0.598	79	13.9	0.0065	5.6	78	131.6	1160	502	96.2	
186	.599		19.2	.0089	10.3	78	181.3	1355	694	98.3	Fuel flow unsteady
187	.598		19.8	.0092	10.6	79	187.8	1385	724	99.2	
188	.600		26.5	.0123	16.8	79	250.3	1575	915	96.1	
189	.601		33.6	.0155	21.8	78	317.0	1755	1095	92.7	
190	.599		42.6	.0197	28.7	78	402.9	1975	1314	89.7	
191	.602		45.3	.0209	32.3	78	426.8	2045	1388	90.1	Blow-out
192	.797	105	14.5	.0051	5.6	77	103.4	1045	388	93.6	
193	.796		21.2	.0074	12.0	76	151.1	1247	592	99.5	
194	.797		30.7	.0107	19.8	75	218.4	1475	817	97.2	
195	.797		41.8	.0146	28.0	75	297.4	1685	1027	92.0	Resonance
196	.797		53.4	.0186	36.5	75	380.3	1875	1212	86.9	
197	.797		56.1	.0195	38.9	73	398.9	1810	1147	78.4	Blow-out
198	.999	132	15.4	.0043	6.5	75	87.2	965	304	86.4	
199	.998		24.0	.0067	13.7	75	136.1	1165	503	93.2	
200	1.001		34.5	.0096	22.2	75	195.4	1375	711	93.7	
201	.997		47.8	.0133	32.1	75	271.5	1575	912	88.5	
202	.990		61.0	.0170	43.1	75	346.4	1645	987	76.3	
203	.990		63.2	.0176	45.2	75	358.8	1600	940	70.1	Blow-out
204	1.299	170	17.7	.0038	8.0	75	77.1	860	200	64.0	
205	1.299		28.2	.0060	17.3	76	123.2	1060	404	82.1	
206	1.300		41.7	.0089	28.5	76	182.1	1265	608	85.3	
207	1.299		66.1	.0141	47.3	76	288.4	1395	735	66.7	
208	1.298		69.9	.0150	50.4	76	305.4	1355	694	59.5	Blow-out
Combustor-inlet total pressure, 8.0 in. Hg abs											
209	0.355	80	13.0	0.0102	7.9	79	207.6	1405	738	92.0	
210	.354		17.2	.0135	11.2	79	275.6	1595	936	89.7	
211	.354		20.8	.0163	14.2	78	333.0	1745	1083	87.5	
212	.352		23.4	.0185	15.9	79	376.6	1760	1104	79.4	Blow-out
213	.557	130	13.9	.0069	8.4	80	141.5	1150	492	87.7	
214	.558		22.1	.0110	15.5	80	224.7	1390	729	84.0	
215	.558		31.9	.0159	23.5	80	324.5	1410	747	60.6	Blow-out
216	.558		29.1	.0145	21.0	80	295.4	1430	767	68.2	
217	.725	170	14.6	.0056	12.4	80	114.2	1075	415	90.9	
218	.726		20.6	.0079	22.4	79	160.6	1175	515	81.2	
219	.727		34.4	.0131	25.0	78	268.0	1185	525	50.5	Blow-out
220	.727		30.3	.0116	22.3	77	236.6	1215	555	60.3	

(d) Ethane; fuel-nozzle configuration 2

Run	Air flow, lb/sec	Combustor-inlet reference velocity (nominal), ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Fuel-nozzle differential pressure, lb/sq in.	Fuel temperature, °F	Heat input, Btu/lb	Mean combustor-outlet temperature, °F	Mean temperature rise through combustor, °F	Combustion efficiency, percent	Remarks
Combustor-inlet total pressure, 14.3 in. Hg abs											
221	0.600	79	14.5	0.0067	0.15	75	137.3	1175	517	95.0	
222	.600		12.3	.0057	.05	75	115.9	1075	420	90.7	
223	.598		21.7	.0101	.64	75	205.6	1310	753	94.7	
224	.602		29.5	.0136	1.13	75	277.8	1580	921	87.5	
225	.602		36.6	.0169	1.37	75	345.2	1815	1158	90.7	
226	.602		48.1	.0222	2.59	75	453.8	2035	1377	84.4	Blow-out, resonance
227	.802	105	14.7	.0051	0	76	104.2	1030	370	88.5	
228	.797		23.8	.0083	.34	76	169.2	1255	598	90.0	
229	.798		34.3	.0120	1.13	76	243.9	1490	830	88.9	
230	.800		48.6	.0169	2.84	76	344.2	1725	1065	83.2	
231	.779		59.0	.0205	4.25	76	418.5	1810	1153	75.3	Blow-out
232	.997	132	15.5	.0043	0	77	88.0	960	301	84.8	
233	.997		29.7	.0083	.64	77	168.7	1195	536	80.7	
234	1.000		44.2	.0123	1.91	77	250.5	1410	750	77.9	
235	1.000		67.1	.0187	5.62	77	380.7	1595	935	65.9	Blow-out
236	1.302	170	17.3	.0037	0	78	75.3	885	228	74.7	
237	1.297		40.6	.0087	1.37	78	177.5	1080	425	60.6	
238	1.298		64.8	.0139	5.04	78	283.1	1270	610	55.9	
239	1.297		73.0	.0156	6.75	78	319.0	1290	633	51.8	Blow-out
Combustor-inlet total pressure, 8.0 in. Hg abs											
240	0.560	130	15.6	0.0077	0.39	73	158.1	1085	422	67.3	
241	.559		19.2	.0095	.54	72	194.5	1165	502	65.7	
242	.559		28.6	.0142	1.52	72	289.7	1265	605	54.3	
243	.559		30.2	.0150	2.10	72	306.4	1260	599	50.9	Blow-out
244	.726	170	16.3	.0063	.29	71	127.6	920	258	50.4	
245	.725		21.5	.0083	1.27	71	168.4	955	296	44.2	
246	.725		27.8	.0107	1.27	71	217.4	985	323	37.7	Blow-out
247	.354	80	13.5	.0106	.29	78	216.2	1335	676	80.6	
248	.354		15.5	.0122	.29	78	248.4	1470	811	85.3	
249	.354		22.8	.0179	1.03	78	366.0	1690	1032	75.9	
250	.354		24.1	.0189	1.52	78	386.4	1670	1013	70.7	Blow-out

TABLE II. - Continued. PERFORMANCE DATA FROM SINGLE COMBUSTOR OPERATING WITH HYDROCARBON AND OXYGENATED-HYDROCARBON GASEOUS FUELS

[Combustor-inlet total temperature, 660° R]

(e) Ethylene; fuel-nozzle configuration 1.

Run	Air flow, lb/sec	Combustor-inlet reference velocity (nominal), ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Fuel-nozzle differential pressure, lb/sq in.	Fuel temperature, °F	Heat input, Btu/lb	Mean combustor-outlet temperature, °F	Mean temperature rise through combustor, °F	Combustion efficiency, percent	Remarks
Combustor-inlet total pressure, 14.3 in. Hg abs											
251	0.800	105	12.7	0.0044	5.0	75	89.8	1010	351	96.8	
252	.798		20.3	.0071	11.0	75	143.7	1210	552	96.9	
253	.800		28.7	.0100	18.6	75	202.9	1420	758	96.1	
254	.799		39.7	.0138	27.1	75	281.3	1640	978	91.5	
255	.799		53.0	.0184	37.5	75	375.0	1885	1223	88.1	
256	.797		66.5	.0232	49.0	75	472.2	2155	1494	87.8	Resonance
257	.797		75.2	.0262	55.8	76	533.5	2310	1649	87.1	Resonance, fuel flow limited
258	.599	79	12.2	.0057	4.5	77	115.3	1125	462	100.3	
259	.598		34.8	.0162	24.0	78	329.6	1770	1111	89.9	
260	.597		45.1	.0210	34.0	77	428.0	2080	1419	91.1	Resonance
261	.597		61.1	.0285	45.8	77	579.6	2415	1754	86.2	Resonance
262	.597		74.8	.0348	54.8	76	708.5	2660	2001	82.8	Resonance, temperature limited
263	1.010	132	12.8	.0035	4.8	76	71.5	925	265	91.3	
264	1.000		26.9	.0075	17.0	75	152.2	1245	585	97.2	
265	1.001		44.6	.0124	30.9	74	252.2	1555	895	92.6	
266	.996		63.0	.0176	46.0	73	357.5	1870	1210	91.1	
267	.998		75.2	.0209	55.6	73	426.2	2035	1375	88.4	Resonance, fuel flow limited
268	1.299	170	13.7	.0029	5.6	73	59.6	870	205	84.4	
269	1.296		30.1	.0064	19.3	73	131.2	1130	473	90.4	
270	1.296		45.8	.0098	34.5	73	200.1	1415	755	97.0	
271	1.297		75.5	.0162	55.7	71	329.4	1735	1074	86.8	Fuel flow limited
Combustor-inlet total pressure, 8.0 in. Hg abs											
272	0.354	80	11.6	0.0091	6.5	79	185.6	1330	667	91.7	
273	.353		15.9	.0125	10.5	79	254.6	1530	867	88.7	
274	.354		19.7	.0154	13.4	79	314.5	1680	1037	87.5	
275	.354		25.8	.0203	18.9	79	413.1	1940	1277	84.2	
276	.354		30.2	.0237	22.8	80	482.6	2105	1442	82.8	
277	.354		34.2	.0268	25.4	80	546.2	2225	1562	80.4	Blow-out
278	.354		34.9	.0274	26.4	80	558.6	2260	1597	80.7	Blow-out
279	.563	130	12.6	.0062	7.1	72	126.3	1125	462	91.6	
280	.563		16.8	.0083	11.1	72	168.7	1280	617	92.9	
281	.556		24.1	.0120	17.4	72	245.3	1495	834	88.3	
282	.558		32.0	.0159	23.9	71	323.9	1705	1044	85.6	
283	.556		43.4	.0217	33.0	71	441.6	1965	1305	80.8	
284	.559		48.1	.0239	37.4	71	486.5	2055	1394	79.2	Blow-out
285	.725	170	13.0	.0050	8.2	72	101.1	995	340	83.4	
286	.725		26.5	.0101	17.9	72	206.6	1295	637	78.8	
287	.725		44.7	.0171	27.7	71	348.8	1525	870	65.7	
288	.725		49.9	.0191	40.2	68	389.9	1595	938	64.0	Blow-out

TABLE II. - Continued. PERFORMANCE DATA FROM SINGLE COMBUSTOR OPERATING WITH HYDROCARBON AND OXYGENATED-HYDROCARBON GASEOUS FUELS

[Combustor-inlet total temperature, 660° R]

(f) Ethylene; fuel-nozzle configuration 2

Run	Air flow, lb/sec	Combustor-inlet reference velocity (nominal), ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Fuel-nozzle differential pressure, lb/sq in.	Fuel temperature, °F	Heat input, Btu/lb	Mean combustor-outlet temperature, °F	Mean temperature rise through combustor, °F	Combustion efficiency, percent	Remarks
Combustor-inlet total pressure, 14.3 in. Hg abs											
289	0.593	79	11.5	0.0054	0	73	109.9	1075	415	94.1	
290	.596		15.6	.0073	.4	73	148.5	1220	560	95.2	
291	.596		21.9	.0102	.4	74	207.6	1425	764	94.8	
292	.597		28.7	.0133	1.0	74	271.6	1635	975	94.3	
293	.599		35.5	.0165	1.5	74	335.7	1800	1140	90.8	
294	.600	105	43.5	.0201	2.4	74	410.3	1995	1335	88.8	
295	.593		52.9	.0248	3.6	75	504.6	2210	1549	85.8	Resonance
296	.591		64.4	.0303	5.5	75	617.9	2460	1800	83.6	Temperature limited
297	.792		12.1	.0042	0	76	86.1	1015	354	101.9	
298	.793		20.2	.0071	.4	76	144.1	2215	558	97.7	
299	.793		28.5	.0100	.7	77	203.3	1420	761	96.3	
300	.794		39.0	.0137	1.9	77	278.1	1635	978	92.5	
301	.795		50.8	.0178	3.3	77	361.8	1855	1194	88.9	
302	.793		62.2	.0218	4.9	78	443.9	2075	1415	87.7	
303	.795		83.2	.0291	9.3	80	592.2	2440	1781	84.9	Resonance, blow-out
304	.998	132	13.7	.0038	0	81	77.6	955	296	94.2	
305	.998		24.7	.0069	.1	81	140.2	1190	532	95.6	
306	.997		42.8	.0119	2.1	81	242.6	1485	825	88.2	
307	.997		61.0	.0170	4.6	81	345.9	1795	1135	87.9	
308	.997		72.9	.0203	7.5	81	413.5	1995	1336	88.2	
309	.996	170	94.1	.0262	11.3	81	534.5	2300	1641	86.5	
310	.996		96.3	.0269	12.3	82	547.2	2335	1675	86.5	Blow-out
311	1.300		21.1	.0045	0	83	92.0	980	326	87.7	
312	1.300		33.9	.0072	.6	82	147.6	1160	503	85.7	
313	1.300		50.5	.0108	2.8	82	219.8	1365	705	82.4	
314	1.298		65.6	.0140	5.5	82	285.8	1565	905	83.0	
315	1.299		84.6	.0181	9.3	83	368.7	1785	1126	81.9	
316	1.300		106.5	.0228	13.8	83	463.4	1965	1308	89.8	Blow-out
Combustor-inlet total pressure, 8.0 in. Hg abs											
317	0.558	130	14.2	0.0071	0.3	71	144.1	1095	436	75.9	
318	.558		18.5	.0092	.8	71	187.7	1295	636	86.4	
319	.557		24.0	.0120	1.2	71	244.0	1445	783	83.1	
320	.558		31.1	.0155	2.1	71	315.1	1635	972	81.5	
321	.558		35.0	.0175	3.0	71	356.3	1770	1108	83.3	
322	.556	170	43.3	.0216	4.5	71	440.6	1940	1278	79.2	
323	.557		48.0	.0239	4.9	71	486.9	1985	1322	75.8	Blow-out
324	.726		15.6	.0060	0	72	121.6	975	316	64.6	
325	.725		25.8	.0099	.6	72	201.5	1160	499	62.8	
326	.723		32.9	.0126	2.5	73	257.5	1350	690	69.1	
327	.725	80	41.0	.0157	3.7	73	320.2	1465	805	65.8	
328	.725		52.0	.0199	5.9	73	406.2	1575	915	60.0	Blow-out
329	.356		10.7	.0083	.3	81	169.6	1260	600	89.8	
330	.354		14.3	.0113	.5	80	229.4	1445	786	88.6	
331	.354		19.0	.0149	1.0	80	303.9	1670	1012	88.0	
332	.354		27.2	.0213	1.8	80	434.7	1975	1318	82.9	
333	.355		36.8	.0288	3.0	80	585.9	2270	1611	77.8	Blow-out

TABLE II. - Continued. PERFORMANCE DATA FROM SINGLE COMBUSTOR OPERATING WITH HYDROCARBON AND OXYGENATED-HYDROCARBON GASEOUS FUELS

[Combustor-inlet total temperature, 660° R]

(g) Acetylene; fuel-nozzle configuration 1

Run	Air flow, lb/sec	Combustor-inlet reference velocity (nominal), ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Fuel-nozzle differential pressure, lb/sq in.	Fuel temperature, °F	Heat input, Btu/lb	Mean combustor-outlet temperature, °F	Mean temperature rise through combustor, °F	Combustion efficiency, percent	Remarks
Combustor-inlet total pressure, 14.3 in. Hg abs											
334	0.796	105	13.2	0.0046	5.4	72	95.2	1025	365	94.8	
335	.802		19.6	.0068	11.2	69	140.6	1210	550	98.1	
336	.801		22.5	.0078	13.6	68	161.9	1280	619	96.5	
337	.800		23.8	.0083	15.0	67	171.7	1315	655	96.6	Fuel flow limited
338	.599	79	11.6	.0054	3.8	80	111.3	1075	414	92.3	
339	.599		16.6	.0077	7.8	81	159.2	1240	580	91.7	
340	.600		21.5	.0099	12.4	83	206.1	1400	740	91.7	
341	.599		25.1	.0116	15.6	85	241.1	1515	855	91.4	Fuel flow limited
342	1.001	132	12.2	.0034	4.4	84	70.3	925	266	92.9	
343	1.000		17.6	.0049	9.2	84	101.4	1015	391	95.5	
344	1.000		24.5	.0068	15.3	85	141.4	1195	536	95.0	Fuel flow limited
345	1.303	170	12.0	.0026	4.5	83	52.9	860	205	94.8	
346	1.296		18.2	.0039	9.3	83	80.9	960	301	91.6	
347	1.296		24.6	.0053	15.6	83	109.3	1070	411	93.4	Fuel flow limited
Combustor-inlet total pressure, 8.0 in. Hg abs											
348	0.556	130	13.2	0.0066	8.6	67	136.6	1165	506	92.6	
349	.555		18.0	.0090	12.4	66	186.8	1330	671	91.1	
350	.558		21.7	.0108	15.9	65	223.9	1440	781	89.4	
351	.559		23.1	.0115	17.8	65	238.2	1490	831	89.8	Fuel flow limited
352	.729	170	13.3	.0051	8.6	65	105.1	1035	377	88.8	Fuel flow erratic
353	.726		16.4	.0063	11.1	65	130.4	1125	468	89.5	
354	.726		21.6	.0083	15.9	65	171.3	1265	606	89.3	Erratic fuel flow
355	.724		22.9	.0088	17.6	64	182.5	1310	650	90.2	Fuel flow limited, erratic
356	.354	80	25.6	.0201	19.4	99	415.7	1925	1264	81.7	
357	.354		19.0	.0149	13.2	98	308.7	1680	1021	86.7	
358	.354		14.4	.0113	9.4	98	234.7	1465	807	88.3	
359	.354		10.6	.0083	6.3	97	172.5	1295	638	93.5	

(h) Acetylene; fuel-nozzle configuration 2

Run	Air flow, lb/sec	Combustor-inlet reference velocity (nominal), ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Fuel-nozzle differential pressure, lb/sq in.	Fuel temperature, °F	Heat input, Btu/lb	Mean combustor-outlet temperature, °F	Mean temperature rise through combustor, °F	Combustion efficiency, percent	Remarks
Combustor-inlet total pressure, 14.3 in. Hg abs											
360	0.596	79	11.8	0.0055	0	111	114.2	1100	439	95.6	
361	.596		18.5	.0086	.05	110	178.3	1305	644	91.4	
362	.597		29.2	.0136	.88	110	281.6	1610	950	87.8	
363	.597		41.5	.0193	2.10	112	400.4	1920	1259	84.3	
364	.597		54.5	.0253	3.81	115	525.0	2260	1598	84.1	
365	.597		72.9	.0339	7.51	116	702.5	2655	1993	81.3	Temperature limited
366	.799	105	12.5	.0044	0	109	90.2	1030	370	101.4	
367	.800		21.1	.0073	.05	107	152.0	1240	582	96.3	
368	.800		35.3	.0123	1.13	105	254.2	1545	885	90.1	
369	.800		50.4	.0175	3.08	104	362.9	1870	1210	88.8	
370	.800		68.1	.0237	6.46	102	490.4	2210	1550	86.8	
371	.995	132	13.1	.0037	0	88	75.7	940	277	90.0	
372	.996		24.6	.0069	0	89	142.2	1180	519	91.4	
373	.998		47.9	.0133	2.84	95	276.6	1590	929	87.3	
374	.996		58.2	.0162	4.30	97	336.7	1800	1139	89.5	
375	.995		75.7	.0211	7.91	96	437.7	2060	1400	86.7	
376	.997		90.3	.0252	11.01	95	521.5	2285	1624	86.1	
377	.997		102.4	.0286	13.31	105	592.0	2470	1809	85.9	Temperature limited
378	1.295	170	16.9	.0036	0	105	75.1	960	299	98.0	
379	1.296		31.8	.0068	.15	107	141.4	1160	499	88.3	
380	1.293		46.7	.0100	2.10	110	208.2	1370	710	86.9	
381	1.295		62.9	.0135	5.28	115	279.7	1585	925	86.0	
382	1.297		76.3	.0163	8.11	117	338.8	1765	1105	86.2	
383	1.299		95.1	.0203	12.11	116	421.7	2010	1350	86.4	Fuel flow limited
384	1.298		45.9	.0098	2.59	110	203.4	1365	705	88.3	
385	.798	105	57.8	.0201	4.55	105	416.8	2005	1344	87.0	
386	.800		82.6	.0287	9.71	103	594.2	2470	1808	85.5	Temperature limited
Combustor-inlet total pressure, 8.0 in. Hg abs											
387	0.559	130	11.7	0.0058	0.05	64	120.3	1095	435	90.0	
388	.558		17.1	.0085	.78	65	176.2	1280	620	88.9	
389	.556		23.0	.0115	1.22	79	237.4	1450	789	85.3	
390	.557		30.5	.0152	2.25	82	315.6	1685	1024	85.1	
391	.557		38.5	.0192	3.47	86	397.7	1870	1208	81.2	
392	.557		46.0	.0224	4.94	93	475.4	2065	1403	80.4	
393	.558		69.5	.0346	9.83	99	717.2	2640	1978	78.7	Temperature limited
394	.558		52.8	.0263	6.65	100	544.7	2245	1583	80.4	
395	.724	170	12.6	.0048	.44	93	99.7	1015	357	88.5	
396	.726		18.6	.0071	.29	90	147.4	1170	509	86.5	
397	.728		32.0	.0122	2.74	89	253.4	1465	806	81.9	
398	.725		46.2	.0177	4.94	91	366.8	1770	1110	80.2	
399	.728		56.1	.0214	8.22	122	444.1	1980	1320	80.3	Exhaust limited
400	.352	80	10.8	.0085	.29	88	176.2	1285	620	89.0	
401	.352		15.1	.0120	.34	87	247.8	1470	814	84.5	
402	.354		20.3	.0159	1.03	87	330.5	1715	1052	83.8	
403	.352		31.1	.0245	2.25	92	508.6	2115	1452	78.2	
404	.354		30.6	.0240	2.49	97	497.6	2110	1453	79.8	
405	.354		36.0	.0283	3.23	108	586.2	2285	1624	77.1	
406	.352		42.3	.0334	4.30	119	691.9	2465	1824	74.8	Temperature limited

TABLE II. - Continued. PERFORMANCE DATA FROM SINGLE COMBUSTOR OPERATING WITH HYDROCARBON AND OXYGENATED-HYDROCARBON GASEOUS FUELS

[Combustor-inlet total temperature, 660° R]

(i) 1,3-Butadiene; fuel-nozzle configuration 1

Run	Air flow, lb/sec	Combustor-inlet reference velocity (nominal), ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Fuel-nozzle differential pressure, lb/sq in.	Fuel temperature, °F	Heat input, Btu/lb	Mean combustor-outlet temperature, °F	Mean temperature rise through combustor, °F	Combustion efficiency, percent	Remarks
Combustor-inlet total pressure, 14.3 in. Hg abs											
407	0.604	79	21.7	0.0100	0	89	191.7	1400	741	99.1	
408	.609		28.6	.0130	12.3	89	250.2	1625	964	100.8	
409	.602		40.2	.0186	19.1	101	356.3	1890	1233	93.1	
410	.601		48.4	.0224	25.1	91	429.6	2135	1473	94.3	
411	.599		65.1	.0302	34.3	117	579.1	2450	1784	87.6	Blow-out, inlet pressure unsteady
412	.600		16.6	.0077	4.3	100	147.2	1255	593	101.8	
413	1.303	170	60.3	.0129	31.8	105	246.6	1485	826	86.8	
414	1.304		51.0	.0109	26.7	97	208.6	1400	741	91.2	
415	1.302		44.9	.0096	22.4	91	183.8	1275	615	85.0	
416	1.302		31.1	.0066	17.1	119	127.0	1170	514	101.5	
417	1.302		22.8	.0049	9.1	117	93.3	965	305	80.9	
418	1.303		18.4	.0039	5.6	111	75.2	875	215	70.3	
419	.799	105	71.1	.0247	37.0	117	474.7	2160	1500	87.4	Resonance
420	.803		54.8	.0190	29.2	101	364.2	1545	1284	95.2	Resonance, inlet pressure unsteady
421	.803		45.8	.0159	24.3	94	304.3	1770	1107	96.6	Resonance, inlet pressure unsteady
422	.801		18.7	.0065	6.0	96	124.5	1160	500	100.6	Resonance, inlet pressure unsteady
423	1.001	132	65.5	.0182	35.1	129	348.7	1850	1194	91.8	Resonance, inlet pressure unsteady
424	1.001		47.2	.0131	24.7	131	251.2	1600	941	97.8	Resonance, inlet pressure unsteady
425	.998		47.7	.0133	24.4	125	254.8	1590	931	95.4	Resonance, inlet pressure unsteady
426	1.002		32.0	.0089	16.1	107	170.2	1345	685	102.5	Resonance, inlet pressure unsteady
427	1.001		20.4	.0057	6.9	96	108.6	1080	420	96.3	Resonance, inlet pressure unsteady
Combustor-inlet total pressure, 8.0 in. Hg abs											
428	0.723	170	36.1	0.0139	29.9	110	266.3	1355	698	67.6	
429	.723		46.9	.0180	26.4	109	345.8	1340	678	51.0	Blow-out
430	.723		41.7	.0160	24.0	101	307.8	1370	712	60.0	
431	.726		29.5	.0113	22.9	95	216.6	1360	699	82.7	
432	.727		18.9	.0072	8.7	95	138.4	1090	429	77.6	
433	.560	130	23.9	.0119	12.5	114	227.4	1440	781	88.6	
434	.565		29.1	.0143	16.5	115	274.6	1620	961	91.8	Inlet pressure unsteady
435	.566		44.1	.0216	24.5	115	415.3	1710	1048	67.7	Inlet pressure unsteady, blow-out
436	.553		35.4	.0177	22.7	111	338.9	1735	1075	84.4	
437	.558		19.8	.0099	9.8	115	189.4	1345	684	92.2	
438	.354	80	14.4	.0113	6.2	93	217.6	1455	794	94.1	
439	.353		19.1	.0150	8.6	95	288.4	1625	960	87.5	
440	.353		22.7	.0178	11.9	98	342.0	1805	1142	89.3	Fuel flow erratic
441	.353		26.8	.0211	15.3	105	404.5	2005	1342	90.3	Fuel flow erratic
442	.352		36.1	.0284	18.9	109	545.4	2185	1513	77.6	Blow-out

(j) 1,3-Butadiene; fuel-nozzle configuration 2

Run	Air flow, lb/sec	Combustor-inlet reference velocity (nominal), ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Fuel-nozzle differential pressure, lb/sq in.	Fuel temperature, °F	Heat input, Btu/lb	Mean combustor-outlet temperature, °F	Mean temperature rise through combustor, °F	Combustion efficiency, percent	Remarks
Combustor-inlet total pressure, 14.3 in. Hg abs											
443	0.601	79	16.8	0.0078	0	114	148.9	1195	536	90.7	
444	.601		33.3	.0154	.88	126	295.3	1735	1076	96.4	
445	.600		44.1	.0204	1.22	134	392.0	1890	1232	84.9	Fuel flow limited
446	1.303	170	17.0	.0036	0	119	69.5	895	235	83.2	
447	1.296		33.7	.0072	0	128	138.7	1080	420	75.7	
448	1.297		39.8	.0085	.15	134	163.7	1100	443	67.9	Fuel flow limited
449	.799	105	17.3	.0060	0	128	115.1	1085	429	92.9	
450	.799		35.7	.0124	.73	133	237.8	1470	809	88.1	Fuel flow unsteady
Combustor-inlet total pressure, 8.0 in. Hg abs											
451	0.557	130	22.2	0.0111	1.0	86	212.8	1310	651	78.2	
452	.567		27.1	.0134	1.5	94	256.9	1405	746	75.0	
453	.567		54.7	.0271	----	96	519.8	1760	520	57.5	Blow-out
454	.729	170	16.5	.0063	0	100	120.7	985	121	66.3	
455	.729		32.3	.0123	.8	110	236.0	1145	236	52.5	

TABLE II. - Concluded. PERFORMANCE DATA FROM SINGLE COMBUSTOR OPERATING WITH HYDROCARBON AND OXYGENATED-HYDROCARBON GASEOUS FUELS

[Combustor-inlet total temperature, 660° R]

(k) Ethylene oxide; fuel-nozzle configuration 1

Run	Air flow, lb/sec	Combustor-inlet reference velocity (nominal), ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Fuel nozzle differential pressure, lb/sq in.	Fuel temperature, °F	Heat input, Btu/lb	Mean combustor-outlet temperature, °F	Mean temperature rise through combustor, °F	Combustion efficiency, percent	Remarks
Combustor-inlet total pressure, 14.3 in. Hg abs											
456	1.310	170	26.5	0.0056	10.8	90	66.0	885	223	80.1	
457	1.310		30.1	.0064	13.2	113	75.1	920	259	83.1	Fuel flow limited
458	1.311		22.4	.0048	8.6	112	55.8	850	189	85.7	
459	.596	79	19.4	.0090	7.8	100	106.1	1080	417	87.2	
460	.600		25.6	.0118	10.3	97	139.1	1175	515	94.9	
461	.596		31.1	.0145	14.3	96	170.5	1285	625	93.6	Fuel flow limited
462	.596		13.5	.0063	3.3	103	74.0	960	298	96.6	
463	.809	105	32.8	.0113	15.3	118	132.3	1155	497	93.5	Fuel flow limited
464	.809		27.2	.0093	11.2	109	109.8	1070	411	92.5	
465	.809		20.5	.0070	6.7	103	82.5	965	306	87.2	
466	.804		12.5	.0043	2.4	99	50.6	860	193	84.3	
467	1.007	132	33.6	.0093	16.2	95	109.0	1080	415	94.6	
468	1.003		26.6	.0074	11.2	102	86.5	985	321	84.0	
469	1.008		19.2	.0053	7.3	104	62.0	900	236	91.6	
Combustor-inlet total pressure, 8.0 in. Hg abs											
470	0.750	170	22.0	0.0082	11.6	107	95.8	985	326	82.1	
471	.750		33.7	.0125	19.3	111	146.4	1160	501	84.4	Fuel flow limited
472	.751		28.3	.0105	15.6	111	122.9	1070	411	87.1	
473	.751		14.8	.0055	6.9	108	64.1	870	210	79.5	
474	.559	130	30.2	.0150	15.9	108	176.6	1280	621	90.0	Fuel flow limited
475	.560		25.5	.0127	13.3	110	148.7	1185	524	88.8	
476	.558		21.2	.0106	10.4	110	123.9	1105	443	87.2	
477	.559		11.7	.0058	4.0	105	68.3	895	231	79.7	
478	.559		17.1	.0085	8.0	105	99.9	1035	376	95.1	
479	.352	80	29.8	.0235	16.2	110	276.4	1560	898	86.1	
480	.351		24.2	.0192	12.2	108	225.1	1415	755	89.3	
481	.352		19.0	.0150	9.6	105	175.8	1305	644	95.1	
482	.351		11.9	.0094	4.5	102	110.7	1075	415	94.4	Inlet pressure unsteady
483	.351		16.8	.0133	7.9	102	155.8	1240	579	95.3	

(l) Ethylene oxide; fuel-nozzle configuration 2

Run	Air flow, lb/sec	Combustor-inlet reference velocity (nominal), ft/sec	Fuel flow, lb/hr	Fuel-air ratio	Fuel nozzle differential pressure, lb/sq in.	Fuel temperature, °F	Heat input, Btu/lb	Mean combustor-outlet temperature, °F	Mean temperature rise through combustor, °F	Combustion efficiency, percent	Remarks
Combustor-inlet total pressure, 14.3 in. Hg abs											
484	0.595	79	40.3	0.0188	1.86	106	221.1	1455	797	95.9	
485	.596		59.0	.0275	3.57	105	323.1	1742	1079	90.7	
486	.596		73.4	.0342	5.28	96	401.7	1950	1293	89.4	Fuel flow limited
487	.598		24.5	.0114	.39	93	133.7	1190	528	99.9	
488	.599		13.0	.0060	.39	92	71.0	947	288	104.8	
489	1.307	170	12.6	.0027	0	90	31.5	775	122	109.6	
490	1.308		55.5	.0118	2.59	108	138.4	1156	497	97.8	
491	1.294		73.3	.0157	4.79	123	184.8	1280	624	87.8	
492	1.303		36.6	.0078	.39	114	91.8	1001	343	92.1	
493	1.303		22.7	.0048	0	106	56.7	866	209	94.3	
494	.997	132	64.5	.0180	3.57	125	211.0	1310	752	93.1	Fuel flow limited
495	.999		47.7	.0133	1.37	120	146.4	1158	572	93.9	
496	.997		34.5	.0096	.39	115	106.3	1025	426	94.1	
497	.999		24.0	.0067	0	111	74.9	913	295	95.5	
498	1.002		9.9	.0028	0	108	33.8	786	151	104.5	
499	.799	105	74.2	.0258	4.79	114	277.0	1535	1036	91.4	
500	.799		55.8	.0194	2.35	116	215.4	1358	810	94.5	
501	.799		34.8	.0121	.64	114	137.3	1135	537	96.6	
502	.798		23.6	.0082	0	107	85.3	981	375	88.5	
503	.798		13.0	.0045	0	104	48.4	839	206	91.4	
Combustor-inlet total pressure, 8.0 in. Hg abs											
504	0.560	130	84.1	0.0417	9.10	104	490.1	2114	1453	83.5	Fuel flow limited
505	.556		57.1	.0286	5.43	111	335.4	1733	1056	87.5	
506	.556		35.9	.0179	1.76	112	210.5	1378	716	86.4	
507	.555		22.8	.0114	.29	110	134.2	1146	482	89.9	
508	.556		12.1	.0061	0	108	71.0	917	254	85.2	
509	.727	170	77.5	.0296	8.12	113	348.1	1700	1042	81.5	Fuel flow limited
510	.727		54.4	.0208	4.69	111	244.5	1436	778	84.5	
511	.727		36.1	.0138	2.01	108	161.8	1209	551	87.5	
512	.730		22.4	.0085	2.93	106	100.1	1012	353	87.8	
513	.727		11.2	.0043	0	104	50.3	850	187	97.5	
514	.727		59.5	.0023	5.43	104	266.8	1490	828	84.2	
515	.355	80	42.3	.0332	7.4	120	389.4	1820	1160	82.2	
516	.355		31.4	.0246	4.7	127	288.9	1620	962	89.3	Fuel flow limited
517	.352		23.9	.0189	2.7	112	221.6	1425	770	93.6	
518	.354		12.0	.0094	5.4	107	110.9	1085	426	95.6	Inlet pressure unsteady
519	.352		16.6	.0131	1.5	109	153.4	1260	604	101.8	Inlet pressure unsteady

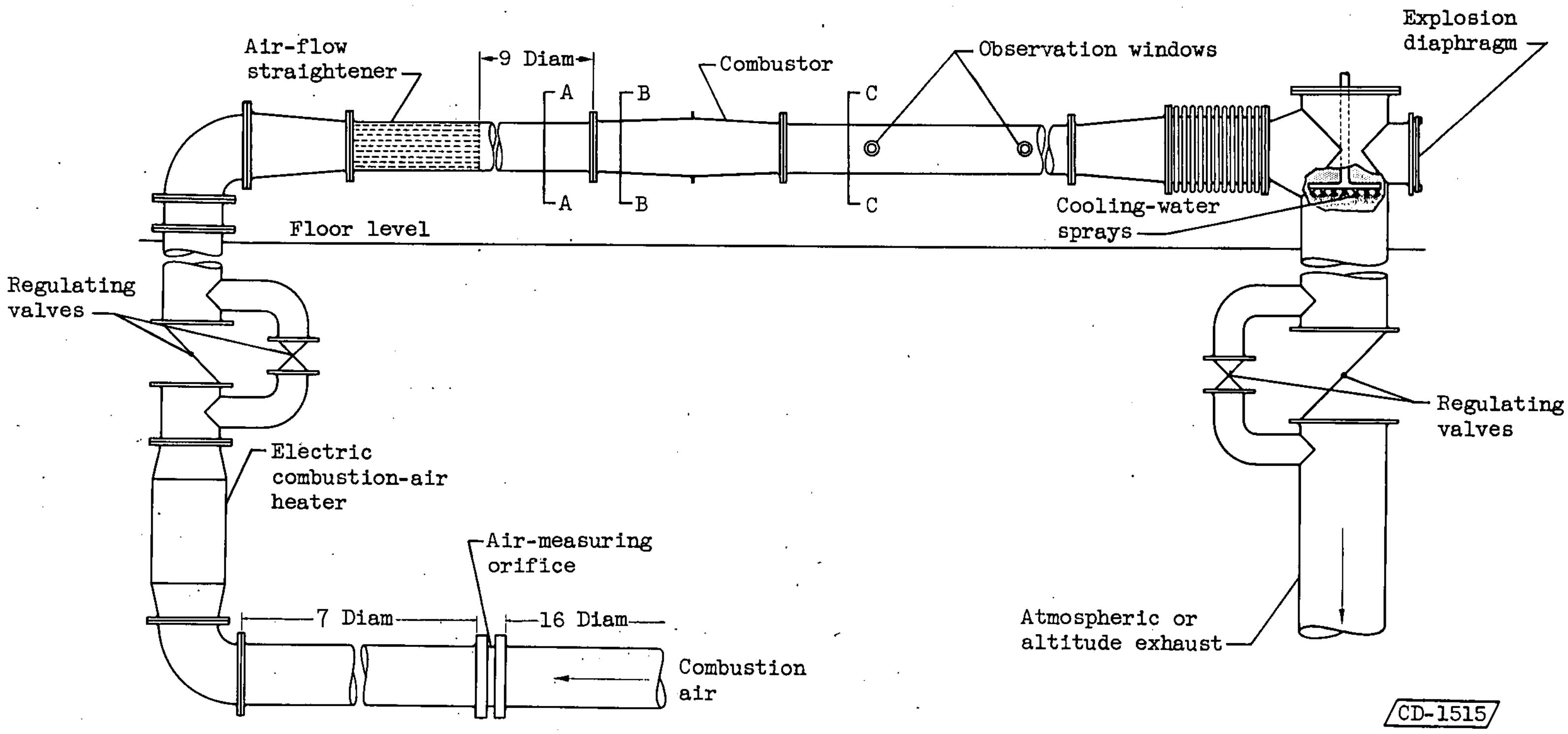


Figure 1. - Single-combustor installation and auxiliary equipment. Instrumentation planes, A-A, B-B, and C-C.

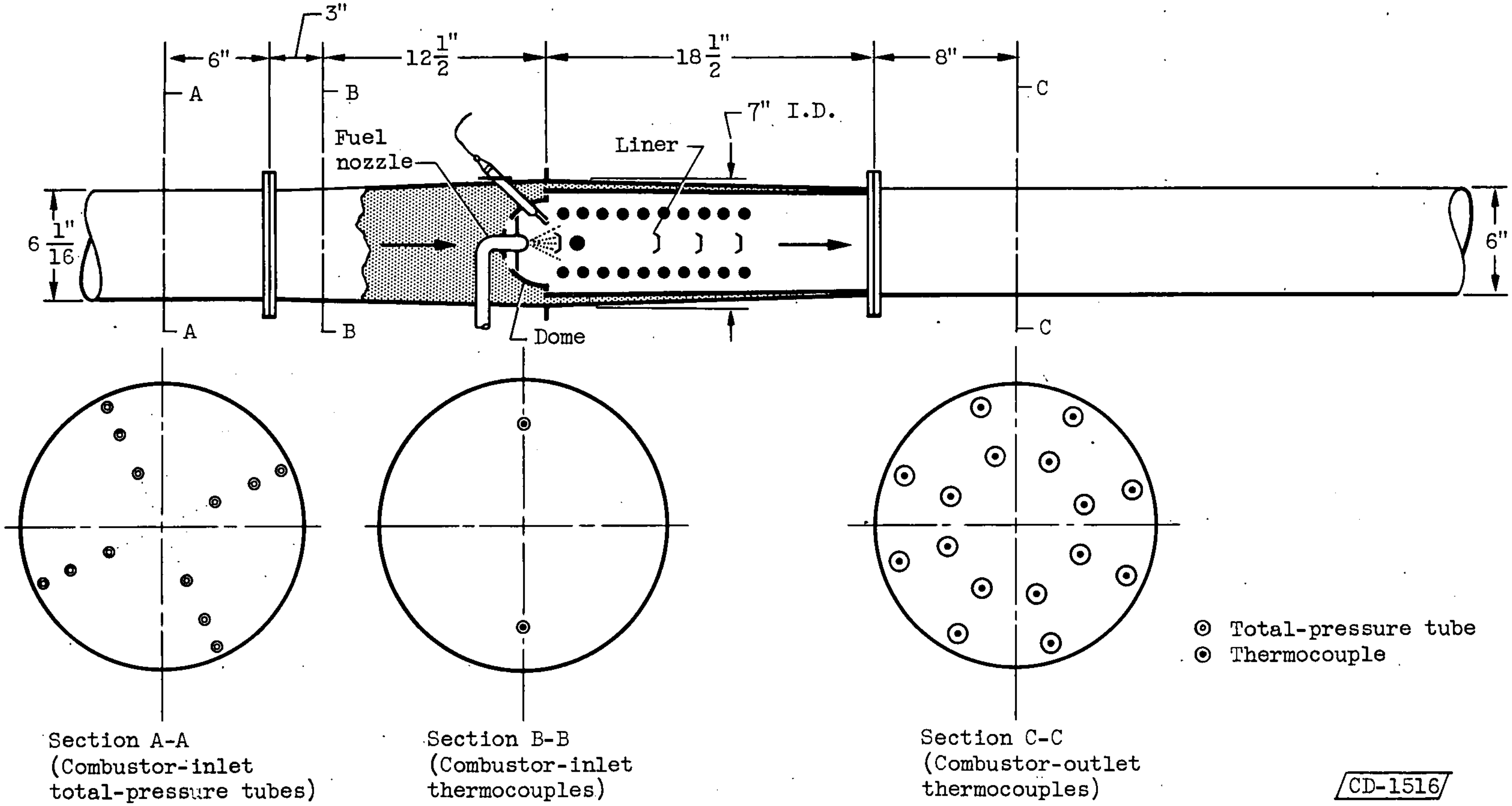


Figure 2. - Cross section of single-combustor installation showing auxiliary ducting and location of temperature- and pressure-measuring instruments in instrumentation planes.

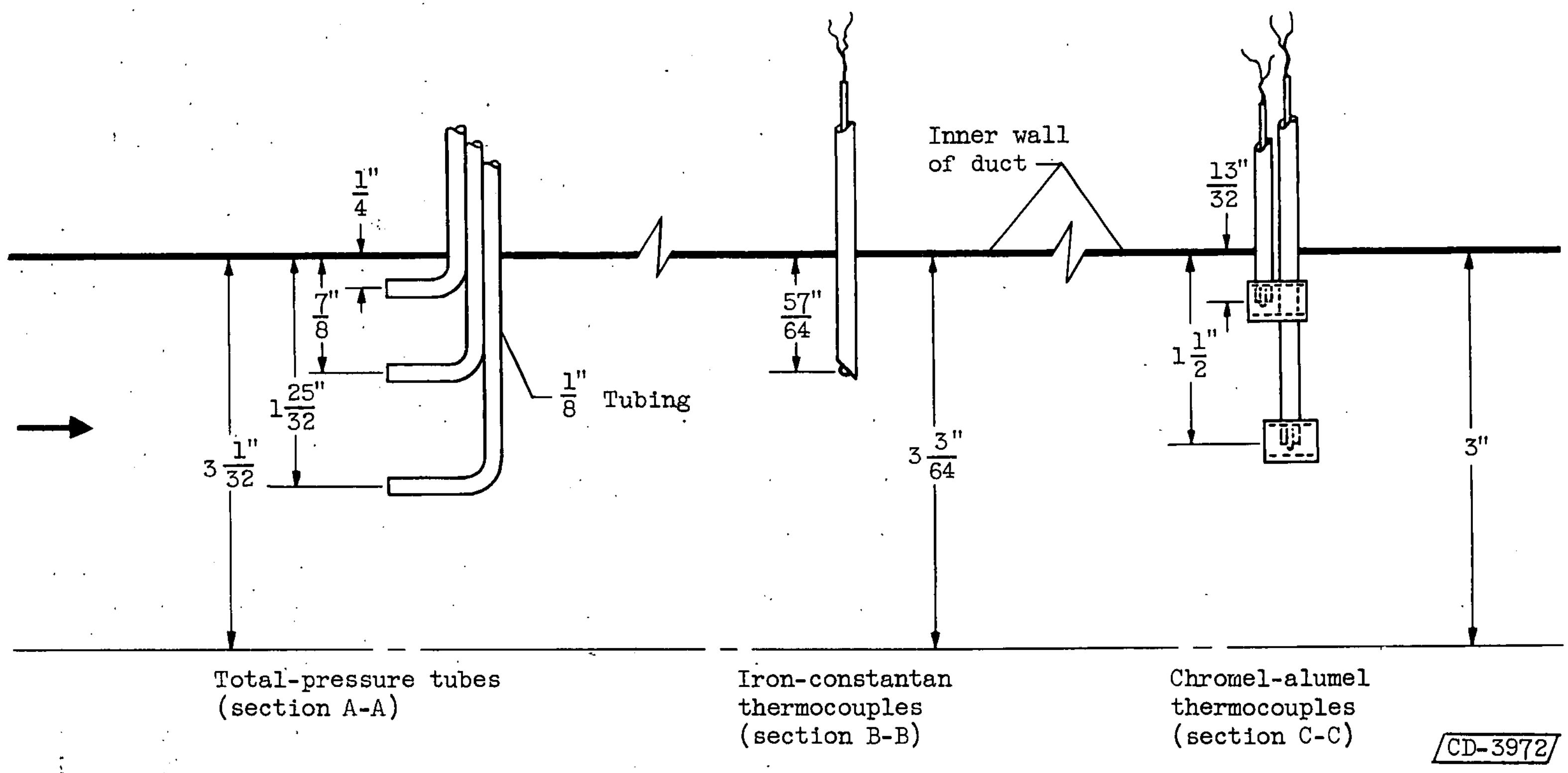


Figure 3. - Construction details of temperature- and pressure-measuring instruments.

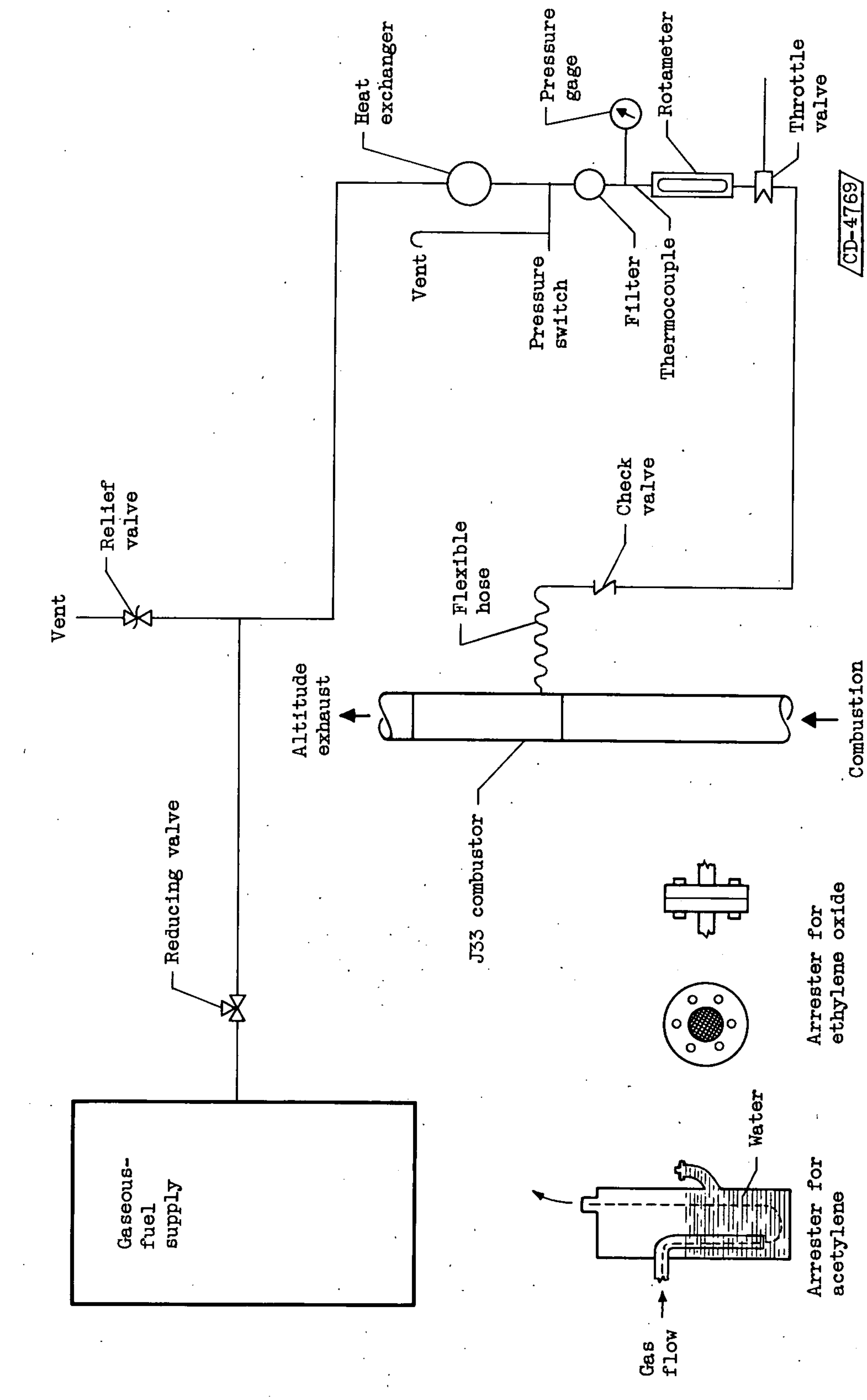
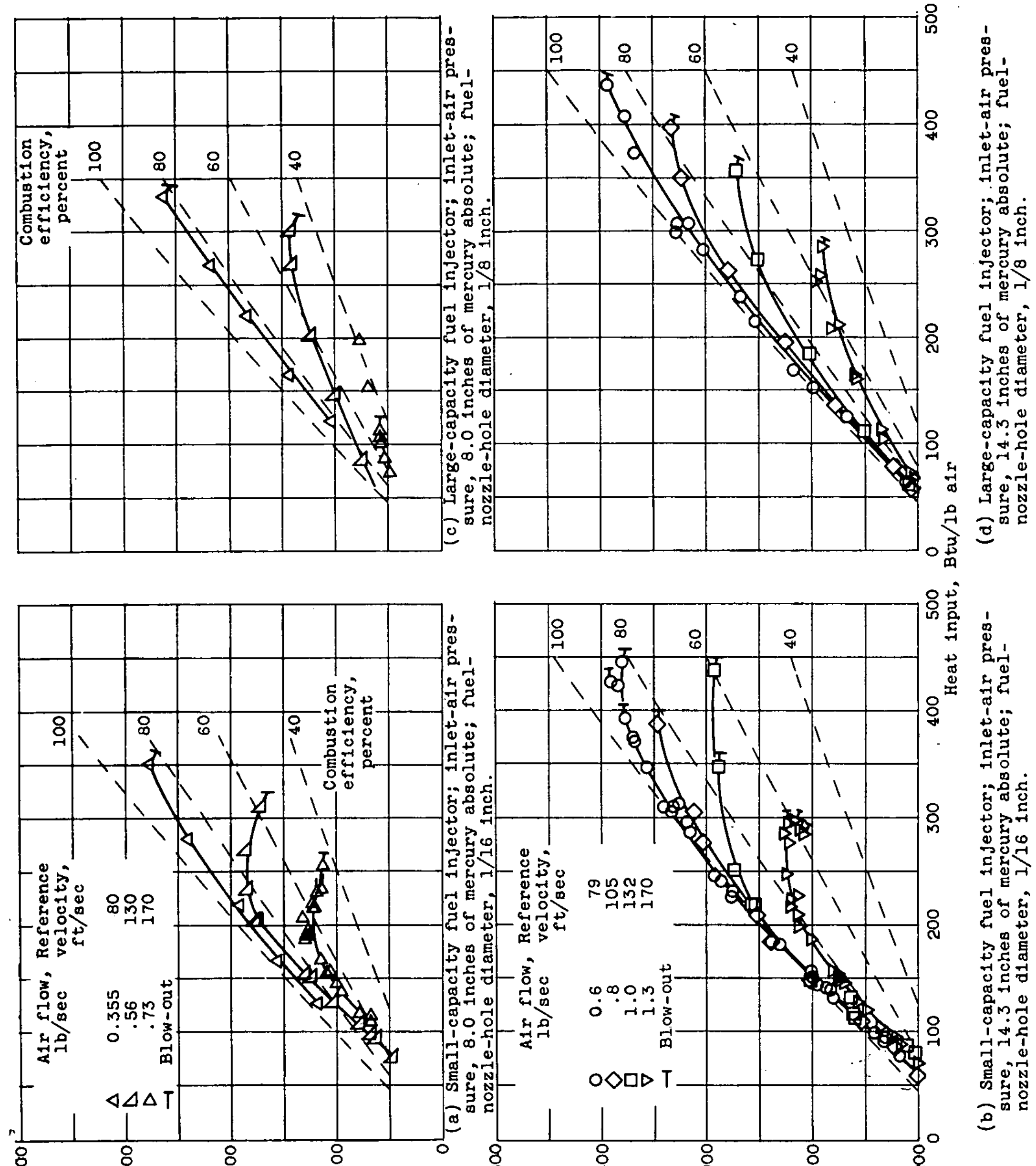


Figure 4. - Schematic diagram of gaseous-fuel system.



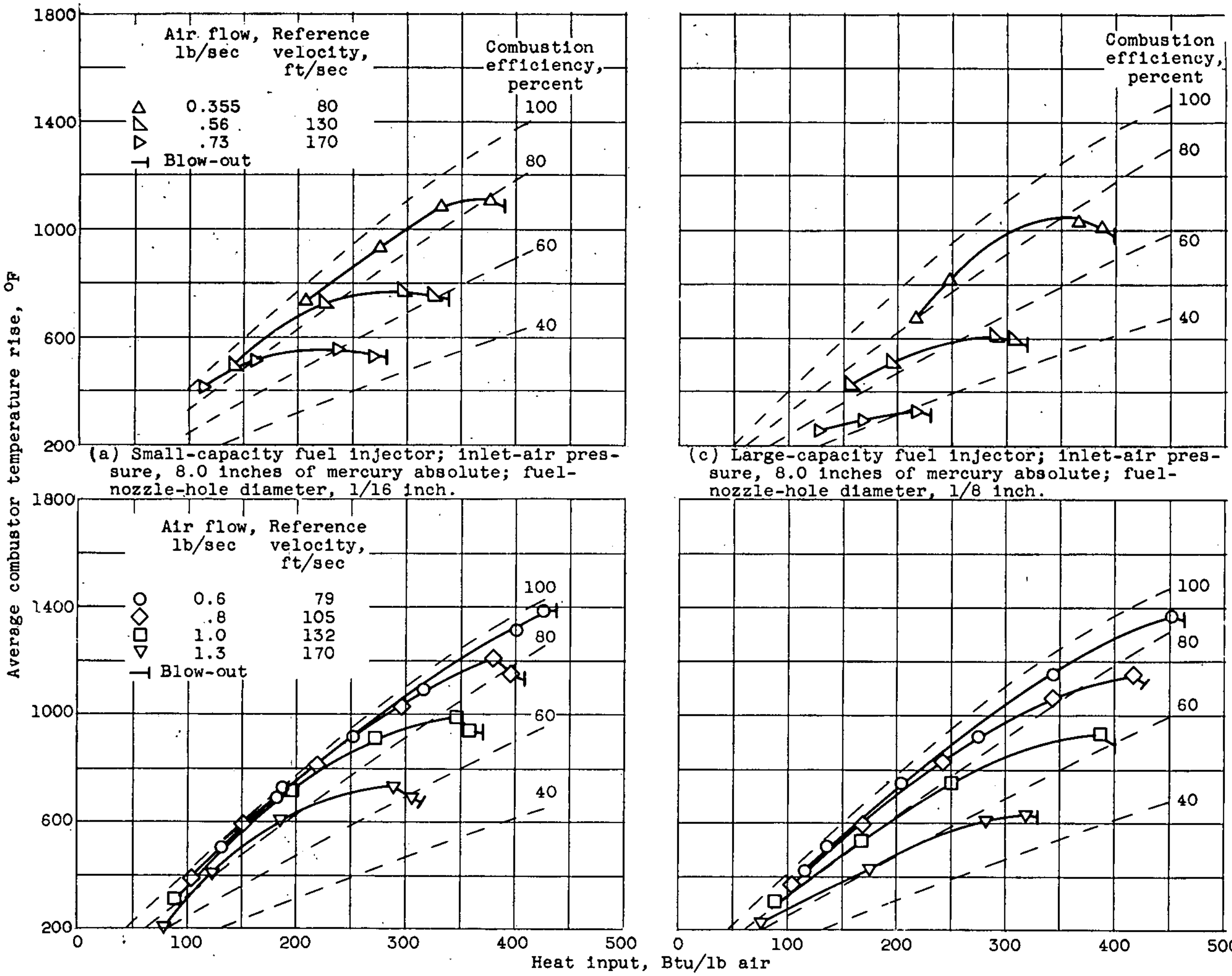
(a) Small-capacity fuel injector; inlet-air pressure, 8.0 inches of mercury absolute; fuel-nozzle-hole diameter, 1/16 inch.

(b) Small-capacity fuel injector; inlet-air pressure, 14.3 inches of mercury absolute; fuel-nozzle-hole diameter, 1/16 inch.

(c) Large-capacity fuel injector; inlet-air pressure, 8.0 inches of mercury absolute; fuel-nozzle-hole diameter, 1/8 inch.

(d) Large-capacity fuel injector; inlet-air pressure, 14.3 inches of mercury absolute; fuel-nozzle-hole diameter, 1/8 inch.

Figure 5. - Variation of average combustor temperature rise and combustion efficiency with heat input for propane. Inlet-air temperature, 200° F.



(a) Small-capacity fuel injector; inlet-air pressure, 8.0 inches of mercury absolute; fuel-nozzle-hole diameter, 1/16 inch.

(b) Small-capacity fuel injector; inlet-air pressure, 14.3 inches of mercury absolute; fuel-nozzle-hole diameter, 1/16 inch.

(c) Large-capacity fuel injector; inlet-air pressure, 8.0 inches of mercury absolute; fuel-nozzle-hole diameter, 1/8 inch.

(d) Large-capacity fuel injector; inlet-air pressure, 14.3 inches of mercury absolute; fuel-nozzle-hole diameter, 1/8 inch.

Figure 6. - Variation of average combustor temperature rise and combustion efficiency with heat input for ethane. Inlet-air temperature, 200° F.

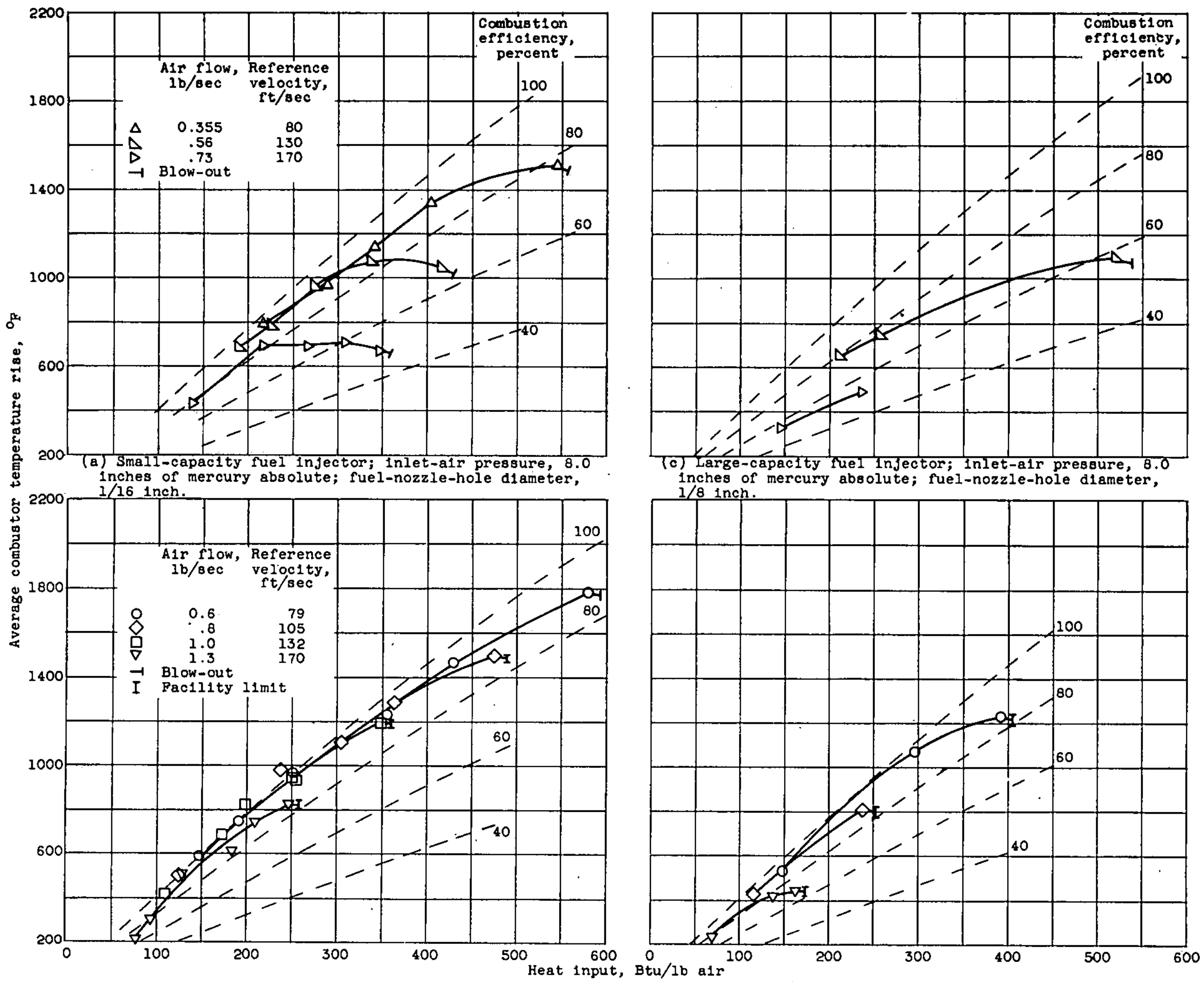
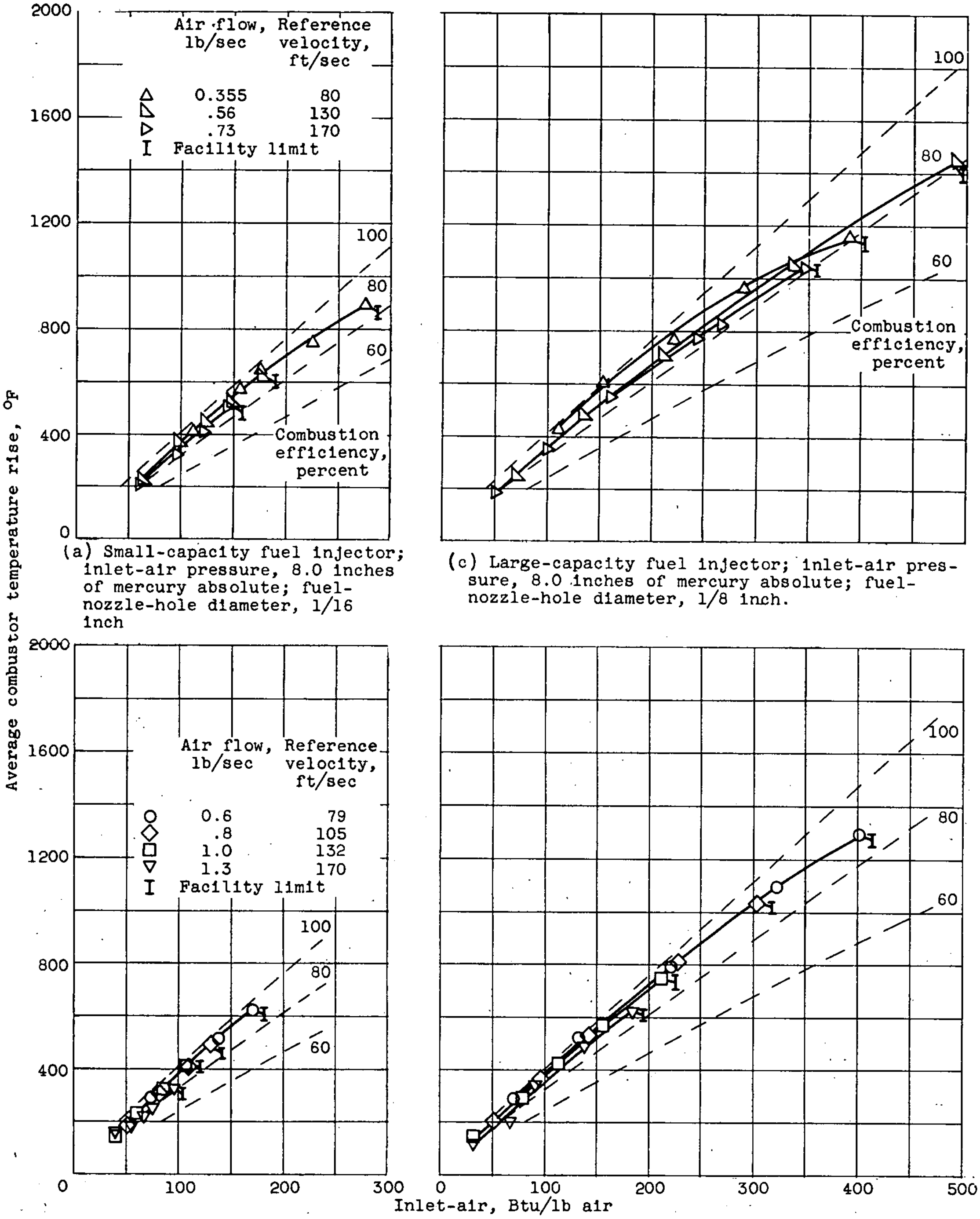


Figure 7. - Variation of average combustor temperature rise and combustion efficiency with heat input for 1,3-butadiene. Inlet-air temperature, 200° F.



(a) Small-capacity fuel injector; inlet-air pressure, 8.0 inches of mercury absolute; fuel-nozzle-hole diameter, 1/16 inch

(b) Small-capacity fuel injector; inlet-air pressure, 14.3 inches of mercury absolute; fuel-nozzle-hole diameter, 1/16 inch.

(c) Large-capacity fuel injector; inlet-air pressure, 8.0 inches of mercury absolute; fuel-nozzle-hole diameter, 1/8 inch.

(d) Large-capacity fuel injector; inlet-air pressure, 14.3 inches of mercury absolute; fuel-nozzle-hole diameter, 1/8 inch.

Figure 8. - Variation of average combustor temperature rise and combustion efficiency with heat input for ethylene oxide. Inlet-air temperature, 200° F.

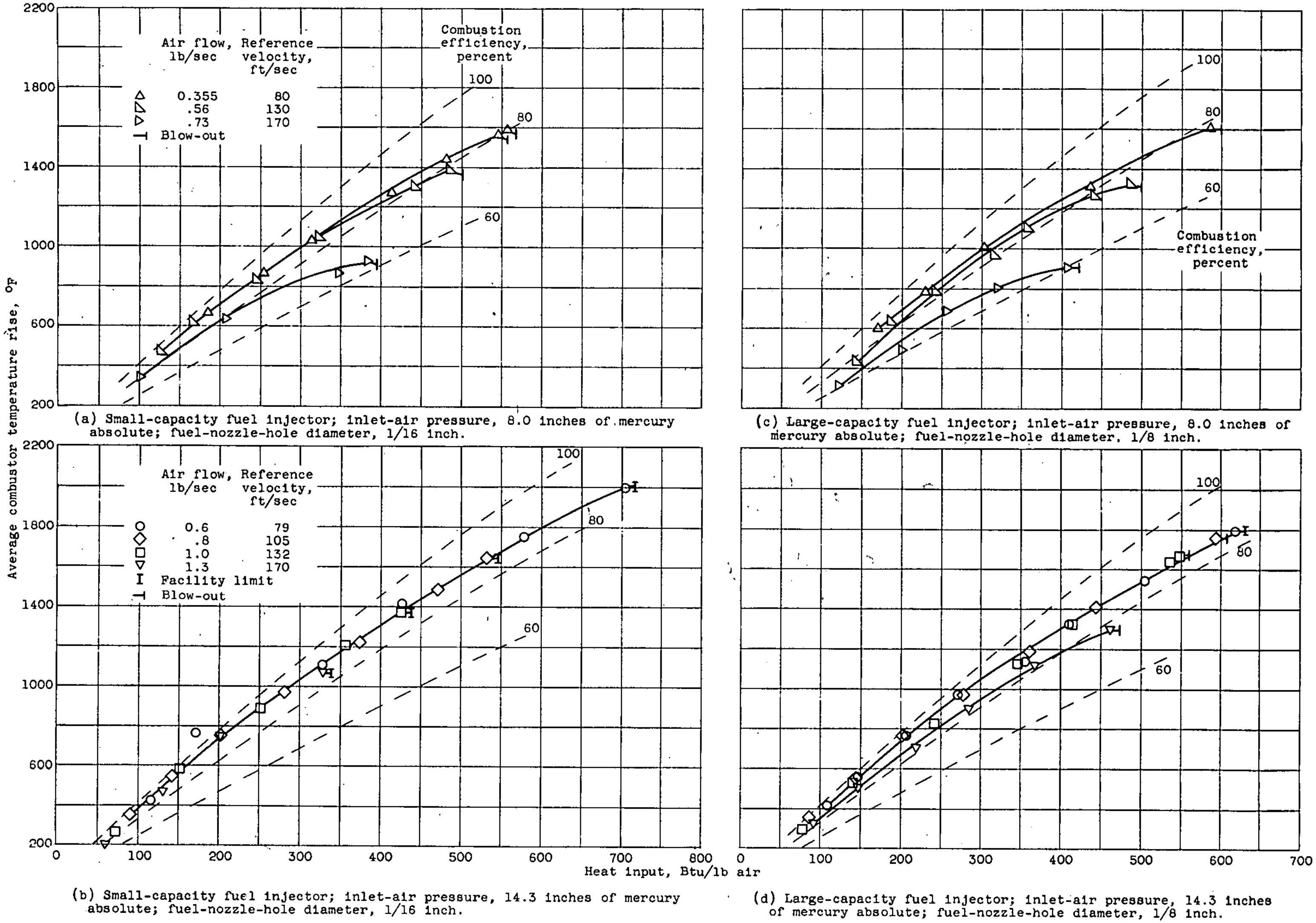
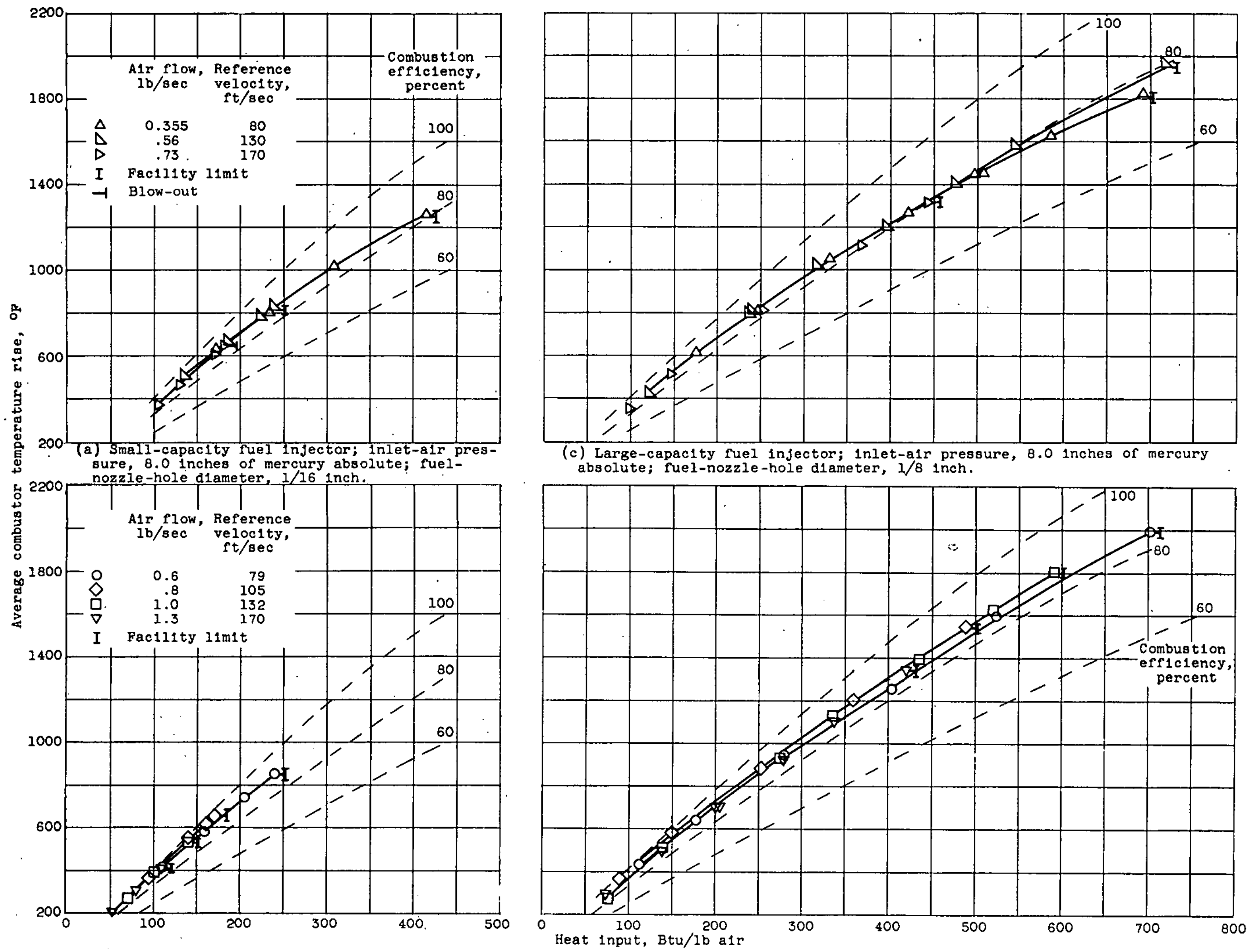


Figure 9. - Variation of average combustor temperature rise and combustion efficiency with heat input for ethylene. Inlet-air temperature, 200° F.



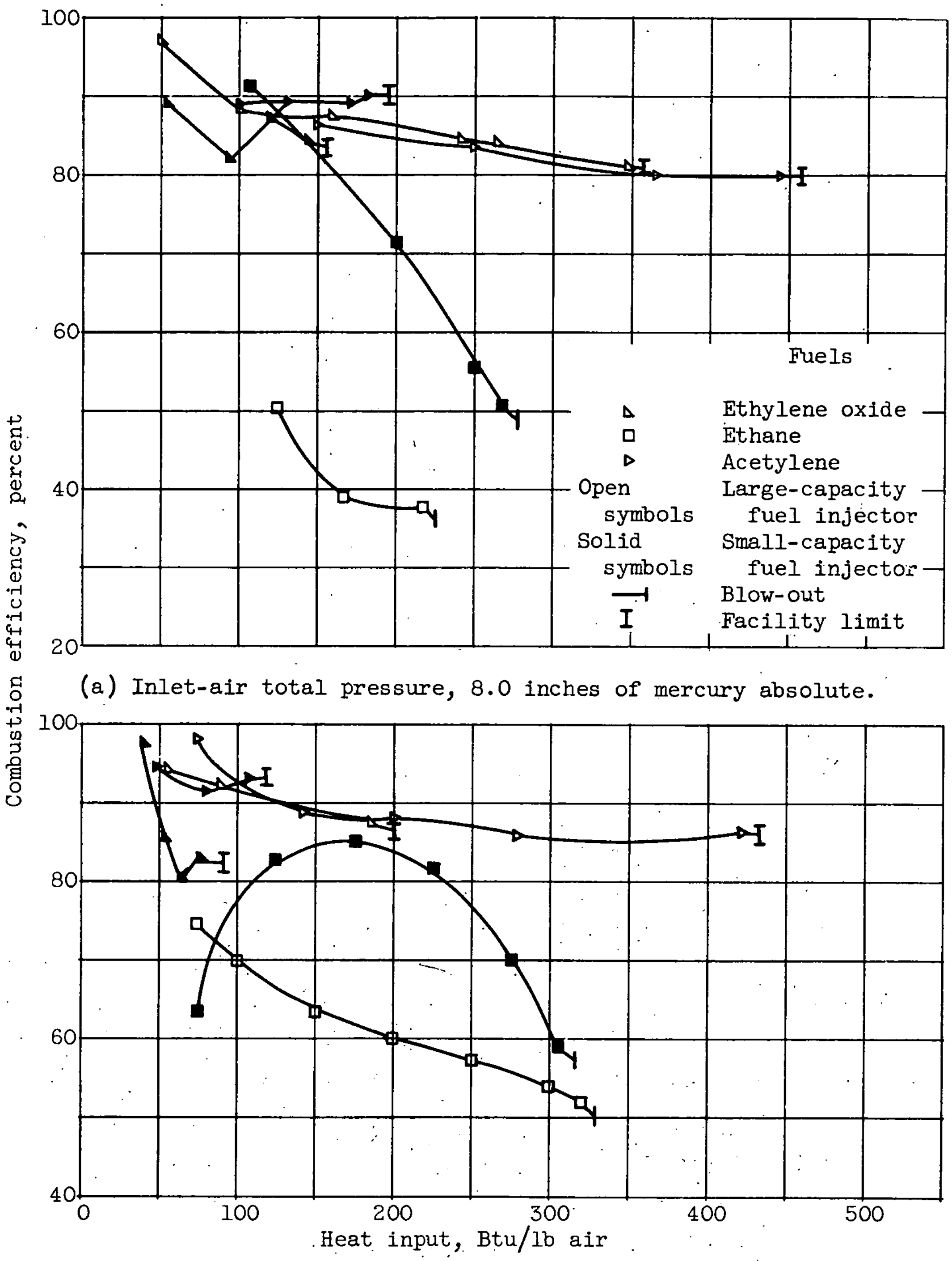
(a) Small-capacity fuel injector; inlet-air pressure, 8.0 inches of mercury absolute; fuel-nozzle-hole diameter, 1/16 inch.

(b) Small-capacity fuel injector; inlet-air pressure, 14.3 inches of mercury absolute; fuel-nozzle-hole diameter, 1/16 inch.

(c) Large-capacity fuel injector; inlet-air pressure, 8.0 inches of mercury absolute; fuel-nozzle-hole diameter, 1/8 inch.

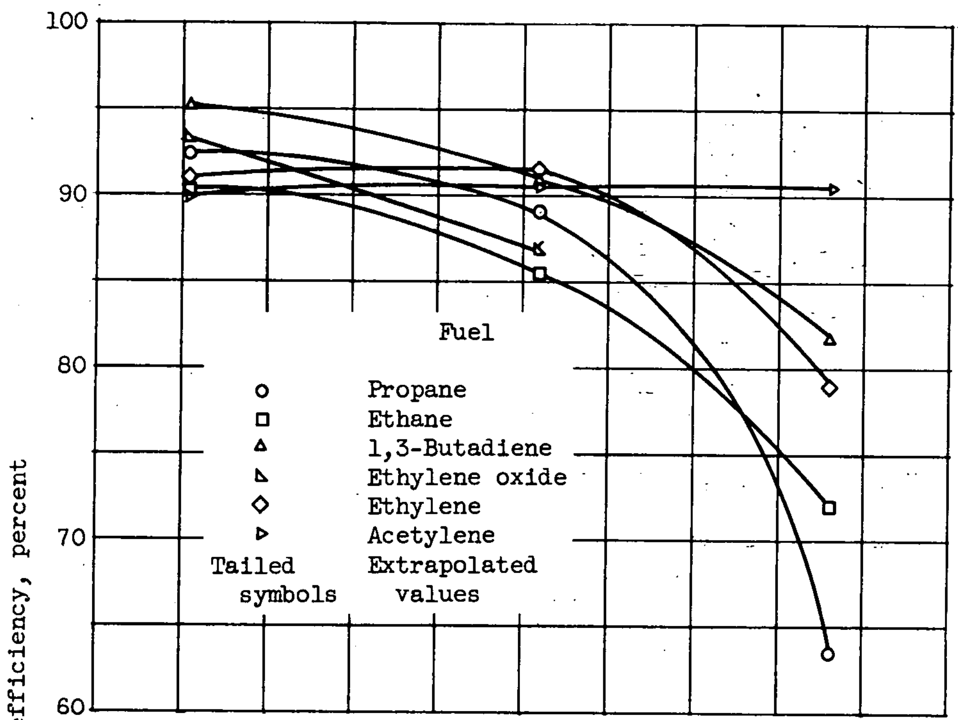
(d) Large-capacity fuel injector; inlet-air pressure, 14.3 inches of mercury absolute; fuel-nozzle-hole diameter, 1/8 inch.

Figure 10. - Variation of average combustor temperature rise and combustion efficiency with heat input for acetylene. Inlet-air temperature, 200° F.

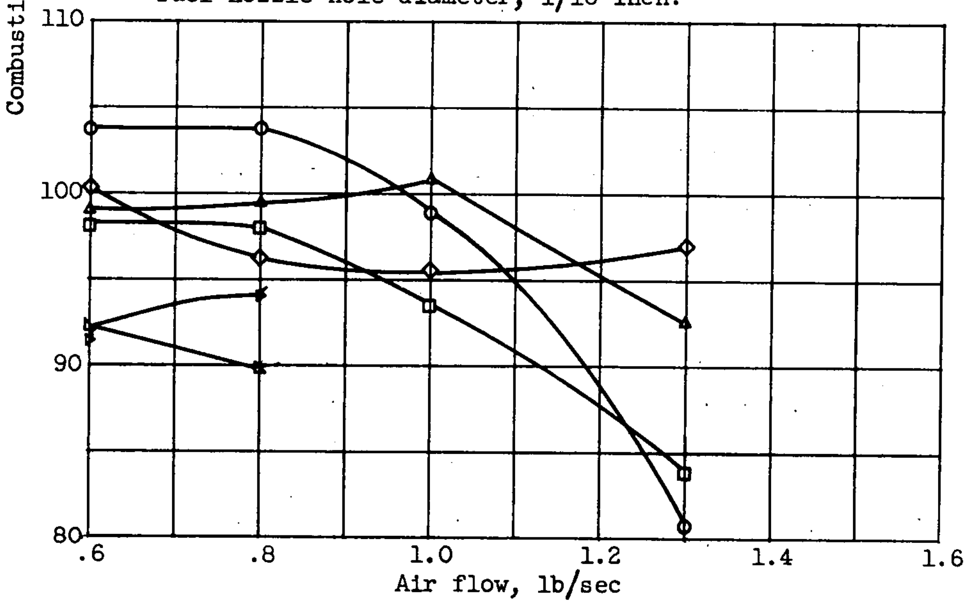


(b) Inlet-air total pressure, 14.3 inches of mercury absolute.

Figure 11. - Variation of combustion efficiency with heat input for three fuels and two fuel-injector configurations. Inlet-air reference velocity, 170 feet per second.

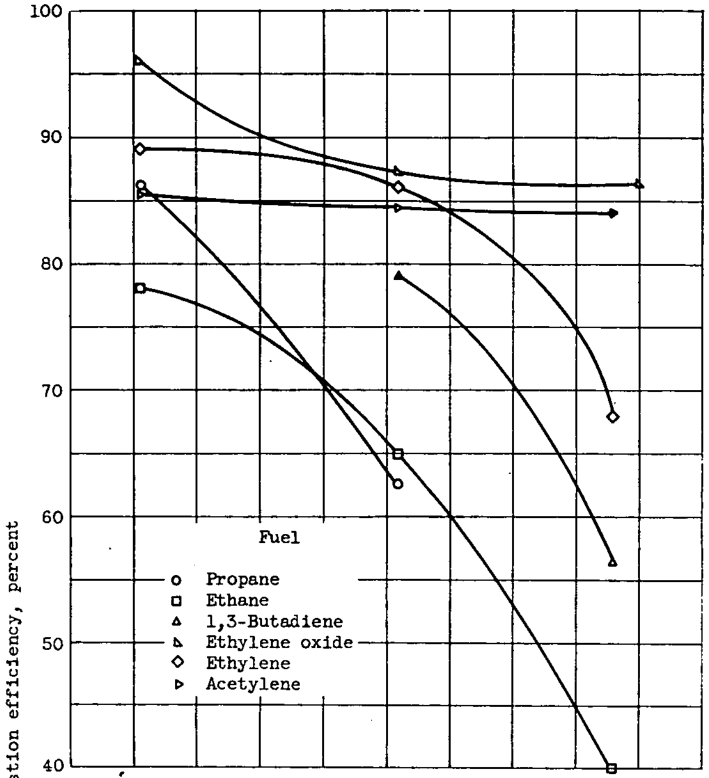


(a) Inlet-air pressure, 8.0 inches of mercury absolute; fuel-nozzle-hole diameter, 1/16 inch.

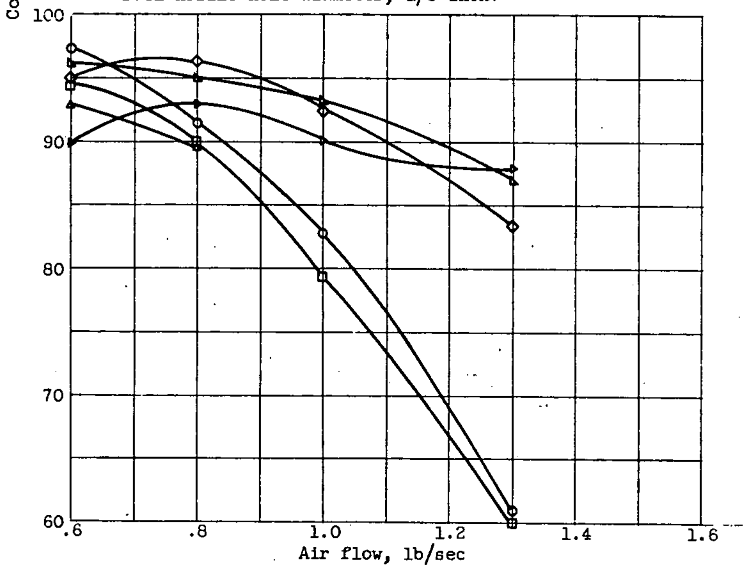


(b) Inlet-air pressure, 14.3 inches of mercury absolute; fuel-nozzle-hole diameter, 1/16 inch.

Figure 12. - Variation of combustion efficiency at heat-input value of 200 Btu per pound of air with inlet-air mass flow for five gaseous hydrocarbon fuels and one oxygenated-hydrocarbon gaseous fuel. Inlet-air temperature, 200° F.

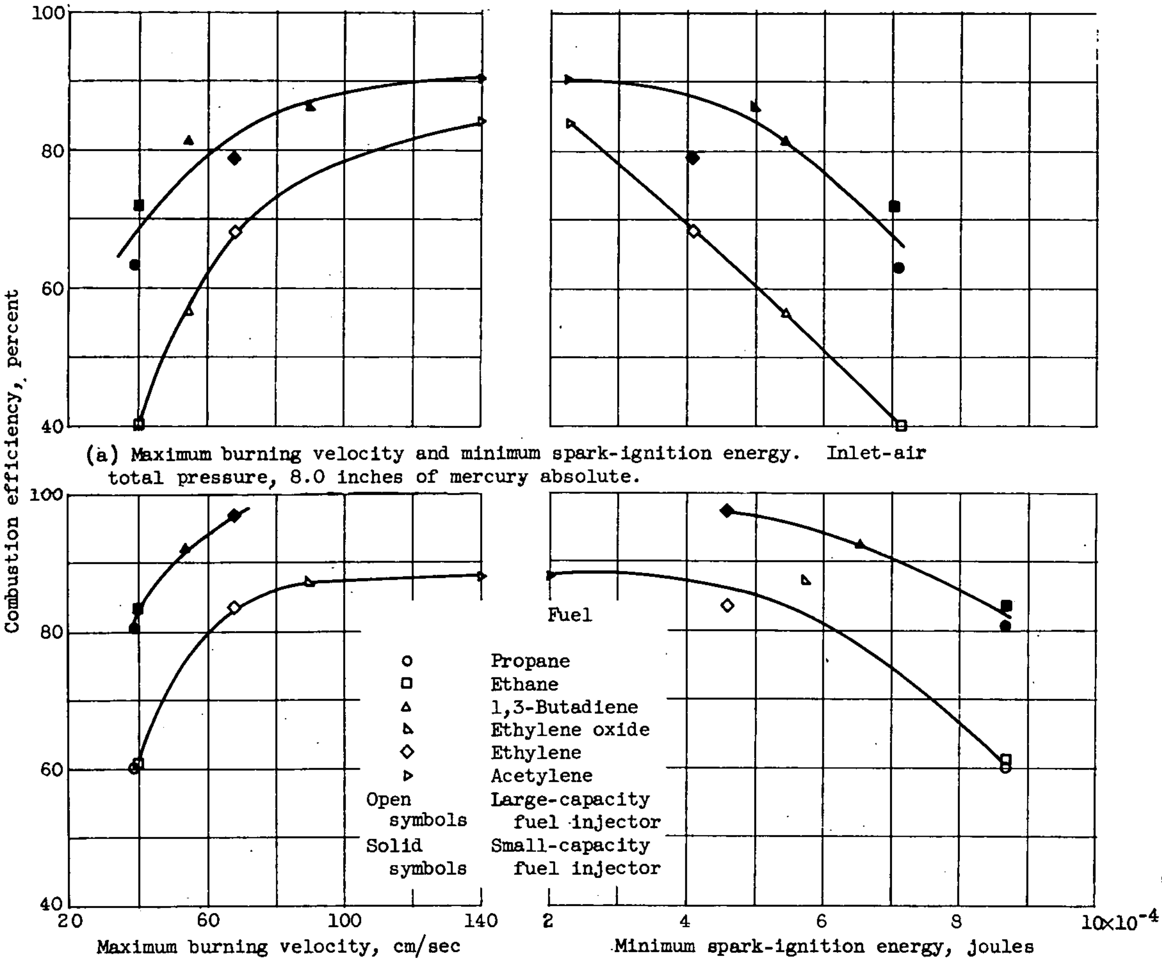


(c) Inlet-air pressure, 8.0 inches of mercury absolute; fuel-nozzle-hole diameter, 1/8 inch.



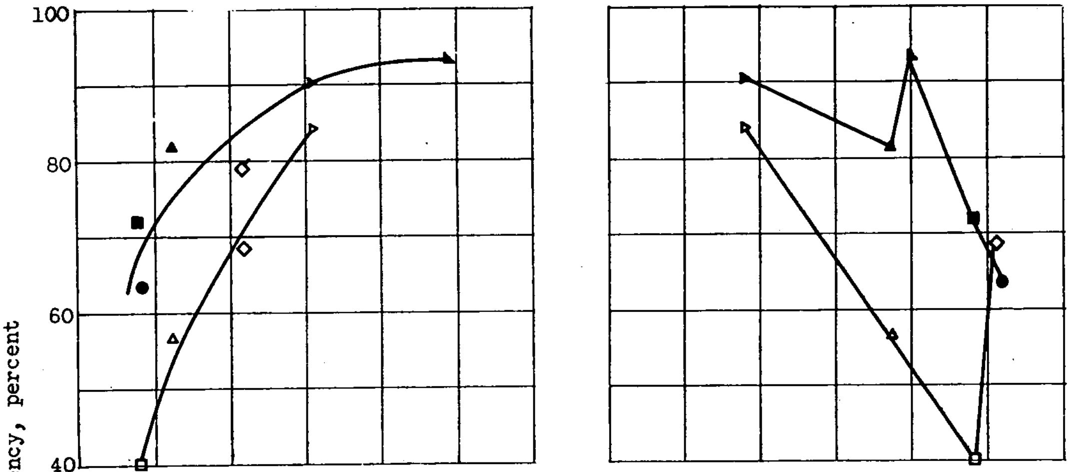
(d) Inlet-air pressure, 14.3 inches of mercury absolute; fuel-nozzle-hole diameter, 1/8 inch.

Figure 12. - Concluded. Variation of combustion efficiency at heat-input value of 200 Btu per pound of air with inlet-air mass flow for five gaseous hydrocarbon fuels and one oxygenated-hydrocarbon gaseous fuel. Inlet-air temperature, 200° F.

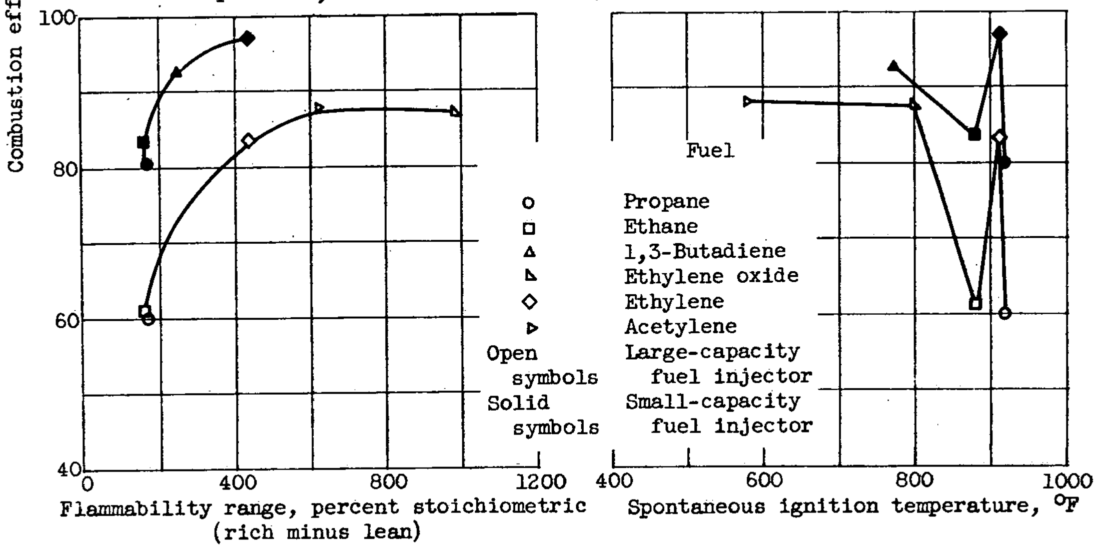


(b) Maximum burning velocity and minimum spark-ignition energy. Inlet-air total pressure, 14.3 inches of mercury absolute.

Figure 13. - Variation in combustion efficiency at heat-input value of 200 Btu per pound of air with fundamental combustion properties. Inlet-air temperature, 200° F; reference velocity, 170 feet per second.



(c) Flammability range and spontaneous-ignition temperature. Inlet-air total pressure, 8.0 inches of mercury absolute.



(d) Flammability range and spontaneous-ignition temperature. Inlet-air total pressure, 14.3 inches of mercury absolute.

Figure 13. - Concluded. Variation in combustion efficiency at heat-input value of 200 Btu per pound of air with fundamental combustion properties. Inlet-air temperature, 200° F; reference velocity, 170 feet per second.

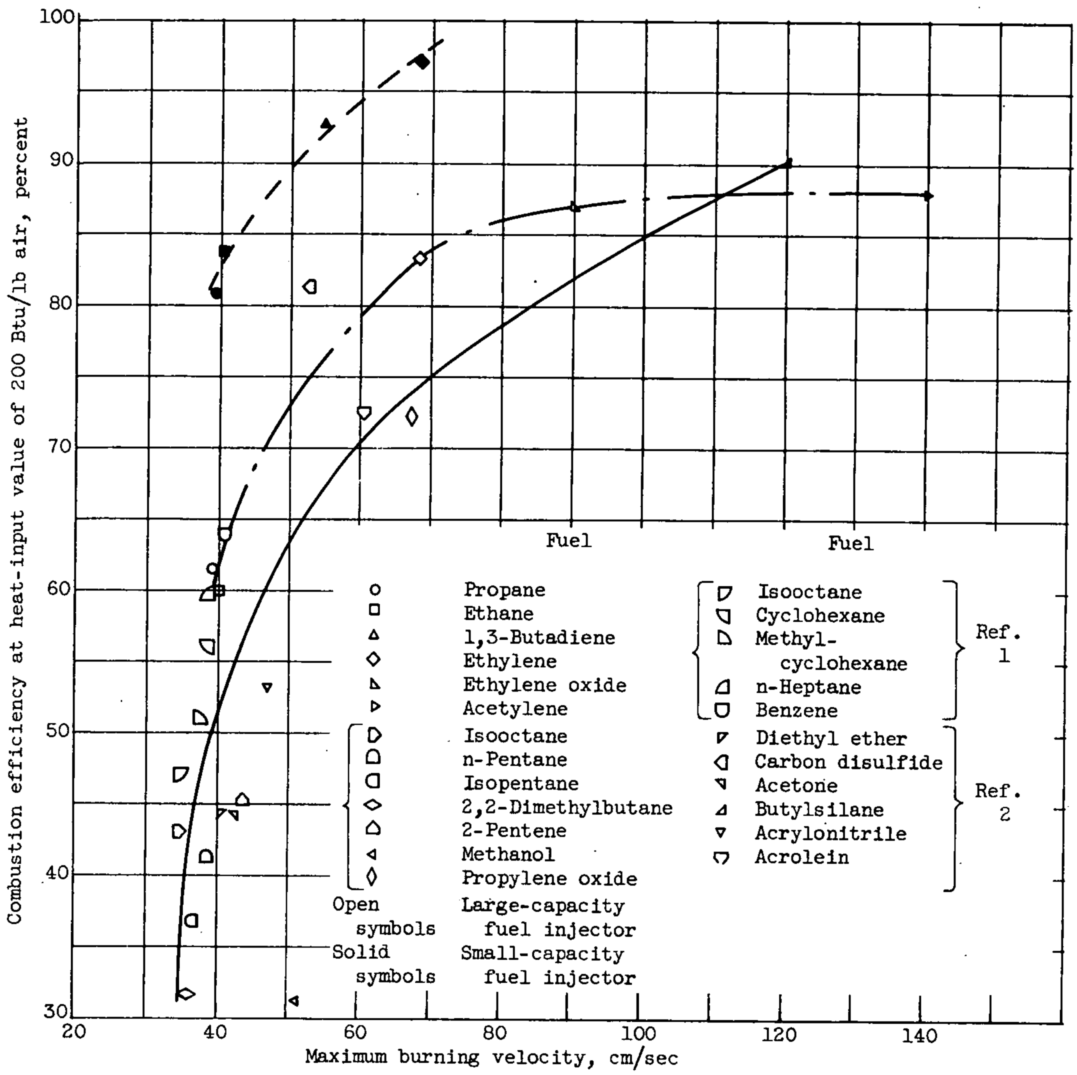


Figure 14. - Variation of combustion efficiency with maximum burning velocity for gaseous and liquid fuels. Inlet-air total pressure, 14.3 inches of mercury absolute; inlet-air temperature, 200° F; inlet-air reference velocity, 170 feet per second.